Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/6180--00-8457

Optical Fire Detection (OFD) for Military Aircraft Hangars: Final Report on OFD Performance to Fuel Spill Fires and Optical Stresses

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May 22, 2000

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 22, 2000	Interim 1999

4. TITLE AND SUBTITLE

Optical Fire Detection (OFD) for Military Aircraft Hangars: Final Report on OFD Performance to Fuel Spill Fires and Optical Stresses

5. FUNDING NUMBERS

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6180--00-8457

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Facilities Engineering Command
Washington Navy Yard
Washington, DC 20374-5065

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Hughes Associates, Inc., Baltimore, MD
**Naval Facilities Engineering Command, Washington, DC

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

Tests were conducted to evaluate the level of performance of commercially available optical fire detectors for use in Navy aircraft hangars. Detectors were evaluated based on response to fuel spill fires and to optical stresses (i.e., potential false alarm sources). The results of the fire detection evaluation have been combined with false alarm immunity criteria into a new optical detector performance specification for Navy aircraft hangars.

14. SUBJECT TERMS

Optical fire detection	Hydrocarbon fuel fires
Spill fires	Performance specification
False alarms	Pool fires

15. NUMBER OF PAGES

333

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

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EXECUTIVE SUMMARY

The Naval Facilities Engineering Command (NAVFAC) has conducted research efforts aimed at improving the design of fire protection systems in military aircraft hangars. The current hangar design strategy is to use low-level (under-wing) AFFF systems activated by optical fire detectors or manual pull stations. Existing Navy requirements limit low-level optical detection to combination ultraviolet and infrared (UV/IR) flame detectors. Since the origination of this requirement, optical fire detection technology has changed significantly and new optical detector designs (e.g., using triple infrared sensors) are on the market. In light of the changes occurring in the field of optical flame detection and the Navy's experience with false alarms with installed detection systems, there was a need to assess optical fire detector performance in military aircraft hangar applications.

The objective of this test program was to evaluate the level of performance of commercially available optical fire detection (OFD) technologies for growing JP-5 and JP-8 spill fires, representative of expected incidents in Navy hangars. The same detectors were also evaluated for their resistance to false alarm sources. The results of these experimental evaluations were combined with a fire threat analysis to develop OFD performance criteria.

A full-scale fire test program was used to evaluate the performance of OFDs representing the different available technologies. The primary objective of this task was to determine the response of optical detectors (provided by participating manufacturers) to a growing spill fire on concrete at a range of distances corresponding to the maximum fire-to-detector spacings in Navy hangars (30.5 to 45.8 m (100 to 150 ft)). Both JP-8 and JP-5 fuel fires were studied. Several gasoline pan fire tests were conducted to provide comparative data for analyzing previous test results with results of this program. Detector performance (i.e., response time vs. distance) was evaluated for the following conditions:

a. Spill scenarios and fire growth rate,
b. Obstruction within the field of view of the detector, and
c. Detector alignment with respect to fire location.

In addition to the spill fire test series, a test program was conducted to determine the susceptibility of the detectors to various optical stresses representative of potential false alarm sources. The basic test procedure was developed by the National Research Council of Canada (NRC) in earlier studies and additional tests for false alarm immunity were added for this program.

A summary of key findings follows:

1. The Navy requirement of using only UV/IR optical fire detectors is not warranted with the current technologies. The use of multiple (triple) spectrum IR detectors can provide improved detection and false alarm immunity over available IR and UV/IR detectors.

2. A relative rank ordering of the OFDs was determined based on the ability of detectors to alarm to the wide range of test scenarios conducted. The results clearly identify OFD6 (3-IR) as the best performer. Detector models OFD1 (UV/IR), OFD3 (3-IR), and OFD4 (2-IR) had mixed results depending on the fire scenarios and test conditions. Detectors OFD2 and OFD5 (both UV/IR) exhibited the greatest limitations.

3. The rank order of performance of the OFDs to the optical stresses is in good agreement with the fire test results. The OFD models OFD3 and 6 (3-IR) responded to a very limited number of nuisance source test conditions. OFD1 (UV/IR) and OFD4 (2-IR) responded to a range of test conditions, and OFD2 and 5 (UV/IR) responded to a wider range of conditions. The models that performed best in the fire tests, also performed well with respect to nuisance alarm immunity.

4. The use of JP-8 compared to gasoline pan fires provided a greater challenge to the optical fire detectors. Based on the tests conducted in this program, there is not a clear recommendation on whether to use JP-8 or JP-5 for performance testing. The use of JP-5 may provide a slightly greater challenge to some detectors with respect to the ability to detect a fire, however JP-8 may be in greater use in the field and more representative of typical hazards.

5. Optical fire detectors were not sensitive to fuel spill geometry for the fires tested.

6. For all fire scenarios evaluated, detector alarm times were directly correlated with the heat release rate of the fires conducted (~100 to 1000 kW). Faster response times were typically achieved with larger fires.

7. Based on the limited comparative test data, it is unclear whether the spill fires provide a unique challenge to the OFDs compared to pan fires. Therefore, the use of pan fires in a detector performance specification test may be adequate. The primary advantage of using pan fires is simplicity of the equipment setup and test procedure. Also special test surfaces are not required as with the unconfined spill fire scenarios. In addition, there are environmental clean-up advantages of using pan fires rather than spill fires.

8. The mass burning rates per unit area for the spill fires were approximately 20 to 25 percent of the published data for pool fires. Because of the much smaller burning rates for these spill fires, it was also observed that the pool diameters for the spill fires were approximately twice as large as would typically be calculated (using published correlations and data) for pool fires of the same heat release rate.

9. Based on a conservative transient heat transfer model, it is believed that an acceptable level of collateral thermal damage to aircraft (i.e., no damage to aircraft greater than 9.1 m from the fire center) can be achieved with an optical fire detection system and low level AFFF system that can control a fire within 90 seconds of ignition.

10. Based on the detector performance test results and the collateral damage assessment, a fire detection performance specification was developed which includes maximum detection times and resistance to false alarm sources.

Optical Fire Detection (OFD) For Military Aircraft Hangars:
Final Report on OFD Performance to Fuel Spill Fires and Optical Stresses

1.0 INTRODUCTION

The Naval Facilities Engineering Command (NAVFAC) is directing research efforts aimed at improving the design of fire protection systems in military aircraft hangars [1,2]. The current emphasis has been to develop a scientific basis for eliminating AFFF from overhead sprinklers and the development of a new AFFF delivery system [2,3]. An integral part of the fire protection system is the means of fire detection. The current specification requires that the hangar foam-water sprinkler systems and supplementary low-level (under-wing) fixed AFFF systems activate based on the activation of a thermal rate-compensated heat detector, a single manual pull station or a single optical detector [4]. Of these, optical detectors are relied upon as the first means of activating under-wing suppression systems.

Currently, the Navy requires that low-level optical detection be accomplished with combination ultraviolet and infrared (UV/IR) flame detectors [4]. It was believed that this requirement was restricting the Navy from using other types of optical detectors which could potentially provide faster response to fires and better immunity to false alarm sources. In the past, UV/IR detectors have provided better immunity to false alarm sources than either single UV or single IR detectors. However, advancements in optical detection technology since the establishment of Navy and DOD criteria have resulted in a number of new optical detectors (e.g., multiple spectrum IR detectors). Limited tests suggest that these optical detectors provide equivalent or improved performance over current UV/IR detectors [5]. It is also important to note that present optical detection criteria allows for the use of any UV/IR detector. The Navy's experience indicates that there is a significant difference in performance between available UV/IR detection systems. Certain detectors are apparently more prone to false alarms yet less reliable during an actual fire. The restriction of using only UV/IR detectors, and the lack of a performance-based standard for optical detectors in hangars, is potentially limiting the use of better detection technologies. It may also be allowing the use of inferior detectors which can lead to increased false alarms and the inadvertent, costly discharge of fire suppression systems.

The two key parameters which characterize the performance of an optical detection system are 1) the ability to detect a fire at the earliest stages of development and 2) the ability to distinguish between real fires and false alarm sources. In addition, the limits of operation with respect to view angle, detection area coverage, and the ability to detect partially obstructed fires is important. Although false alarm immunity is a primary consideration in the selection of a detection system, to date there has been no false alarm immunity criteria against which optical detectors were evaluated. Recent work conducted at the National Research Council of Canada (NRC) has addressed this issue. Researchers at NRC have developed test protocols and apparatus to evaluate the false alarm immunity of optical fire detectors [6].

Manuscript approved April 19, 2000.

With the exception of the Navy's recent high bay hangar fire testing, optical detectors have neither been tested nor approved for JP-5 fires (limited tests have been conducted with JP-8 pan fires). Present Listings from national testing laboratories are for pool fires in pans of prescribed sizes. Optical detectors have never been evaluated for growing spill fires on concrete which are representative of an actual fuel spill fire in a hangar. With new detection technologies available, there was a need to comparatively assess the performance of the various optical fire detectors with respect to realistic fuel spill fire events.

2.0 OBJECTIVE

The objective of this test program was to evaluate the level of performance of commercially available optical fire detection (OFD) technologies for growing JP-5 and JP-8 spill fires, representative of expected incidents in Navy hangars. The same detectors were also evaluated for their resistance to false alarm sources. The results of these experimental evaluations were combined with a fire threat analysis to develop OFD performance criteria.

3.0 APPROACH

A full-scale fire test program was used to evaluate the performance of OFDs representing the different available technologies. The primary objective of this task was to determine the response of optical detectors (provided by participating manufacturers) to a growing spill fire on concrete at a range of distances corresponding to the maximum fire-to-detector spacings in Navy hangars (30.5 to 45.8 m (100 to 150 ft)). Both JP-8 and JP-5 fuel fires were studied. Several gasoline pan fires were conducted to provide comparative data for analyzing previous test results with results of this program. Detector performance (i.e., response time vs. distance) was evaluated for the following conditions:

a. Spill scenarios and fire growth rate,
b. Obstruction within the field of view of the detector, and
c. Detector alignment with respect to fire location.

In addition to the spill fire test series, a test program was conducted to determine the susceptibility of the detectors to various optical stresses representative of potential false alarm sources. The basic test procedure developed by NRC along with additional tests for false alarm immunity were conducted at NRC. The optical stress immunity tests are discussed in Section 7.

4.0 DEFINITIONS

Confined Spill Fire	A continuous fuel spill test fire burning in a 15 cm wide channel (see Sec. 5.2.2).

DLS	Direct line of sight.
Fixed Quantity Spill Fire	A test fire resulting from igniting a fixed quantify of fuel spilled on a concrete pad. The spill was allowed to reach a near-quiescent state before ignition (see Sec. 5.2.3).
FOV	Detector field of view.
HOA	Horizontal off-axis; detector alignment with respect to fire source (see Sec. 5.1).
HVOA	Horizontal and vertical off-axis; detector alignment with respect to fire source (see Sec. 5.1).
IR	Infrared
OFD	Optical Fire Detector
OFD Model	One of six optical fire detector models provided by three manufacturers. The detector models are designated as OFD1, OFD2, OFD3, OFD4, OFD5 and OFD6. Individual detectors are designated as OFD#A through OFD#F. The letter designation indicates the detector mounting location and orientation (see Table 3, p.25).
Pan Fire	A pool fire conducted by burning a fixed quantity of fuel in a steel pan (see Sec. 5.2.4).
Response	The event in which the OFD signals the presence of a fire.
Unconfined Spill Fire	A continuous fuel spill test fire allowed to spread freely on a concrete pad (See Sec. 5.2.1).
UV	Ultraviolet.
UV/IR	An optical fire detector which detects ultraviolet and infrared radiation.
2-IR	An optical fire detector which detects infrared radiation in two regions of the IR spectrum.
3-IR	An optical fire detector which detects infrared radiation in three regions of the IR spectrum.

5.0 SETUP AND PROCEDURE FOR FIRE TESTS

5.1 General Setup

Tests were conducted at the National Fire Laboratory of the National Research Council Canada. The test facility was a 55 x 30.5 x 12.5 m high (180 x 100 x 41 ft) building with natural lighting around the perimeter through 1.2 m high glass windows located 6 m above the floor. Accept where noted, all mechanical ventilation and electrical lighting in the test facility was turned off during the tests. The test facility provided an enclosed space in which optical fire detectors could be positioned without obstruction at far distances from a fire.

The general setup consisted of exposing six arrays of detectors to a target fire radially located at a distance of 30.5 m (100 ft) and 45.8 m (150 ft) away from the detector arrays. Figures 1a-1d show schematics of the general test setup. The detectors were mounted on two masts, one at 30.5 m (100 ft.) and one at 45.8 m (150 ft.) from the fire (i.e., center of concrete pad). Each mast contained three arrays of detectors positioned 2.7, 3, and 3.4 m (9, 10, and 11 ft) above the floor. Detector arrays 1, 2 and 3 were located at a distance of 30.5 m away from the fire. Array 1 was positioned so that the fire was in the direct line of sight of the detectors field of view. All detectors were aligned to a target 1.2 m above the center of the concrete pad (Figure 1b). Array 2 was positioned 40 degrees off-axis in the horizontal plane of the direct line of sight of the Array 1 detectors (see Figure 1c). A 40 degree off-axis angle was the manufacturer specified FOV ($\pm$ 45) minus 5 degrees for all, but one, detector. The exception was stated to have a larger field of view. Evaluating all detectors at the same limits (and within the manufacturer stated fields of view) provided a fair comparison of technologies while also determining the capabilities of the OFDs. Array 3 detectors were positioned off-axis in the horizontal plane and the vertical plane at an angle of 40 degrees from the direct line of sight (Figure 1d). Viewing from the detector toward the fire, the Array 3 OFDs were rotated downward and to the left such that the angle between the detectors direct line of sight and the direct line of sight to the fire (Array 1) was 40 degrees.

Detector arrays 4, 5 and 6 were located at a distance of 45.8 m away from the fire. Detector arrays 4, 5 and 6 were aligned in the same manner as detector arrays 1, 2 and 3, respectively. Detector arrays 4, 5, and 6 were positioned approximately 5 degrees apart from arrays 1-3 (see Figure 1a). This setup allowed the detectors to be similarly positioned without the forward– most arrays blocking the view of the detectors at 45.8 m (150 ft) away from the fire.

The spill fires were conducted in front of a flat black background. The fires were created on a 10 cm (4 in.) thick concrete slab 4.6 x 4.6 m (15 x 15 ft). Figures 2 and 3 show photographs of the test site with the concrete slab. The surface of the concrete was trowel finished and level (to within 3 mm). The slab cured for 19 days before it was finished. The surface of the concrete was finished with Tennant ECO-HPS floor coating, pigmented white. This polyurethane floor covering is the system that is representative of approximately 75 percent of the existing Navy hangars [7].

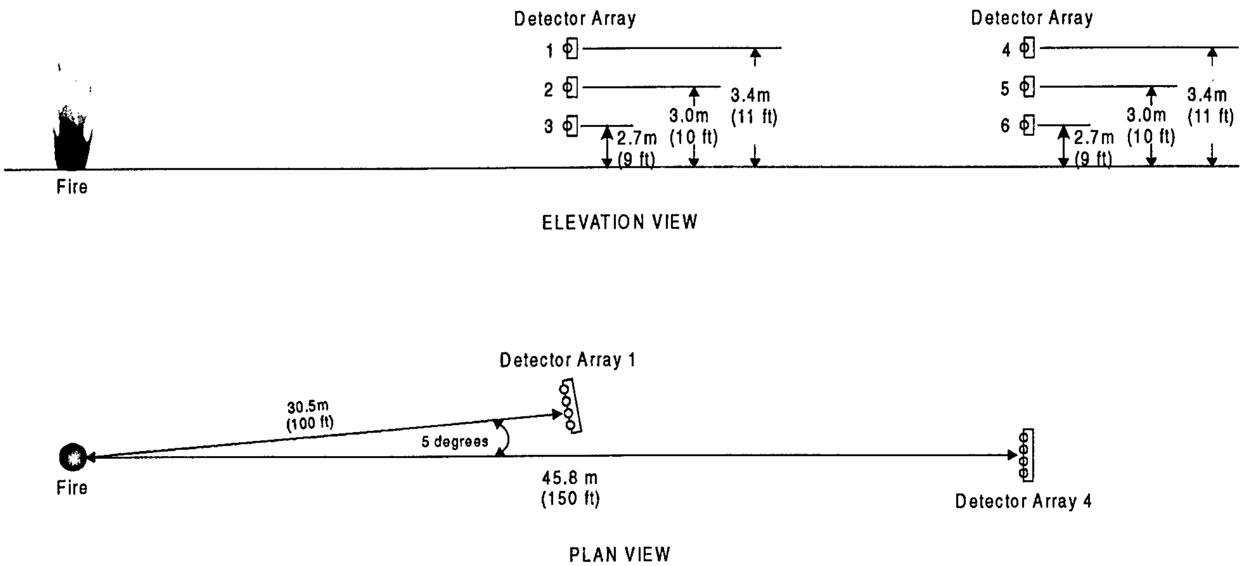


Fig. 1a – Schematic of general test setup
(for clarity, off-axis detector arrays are not shown on plan view)

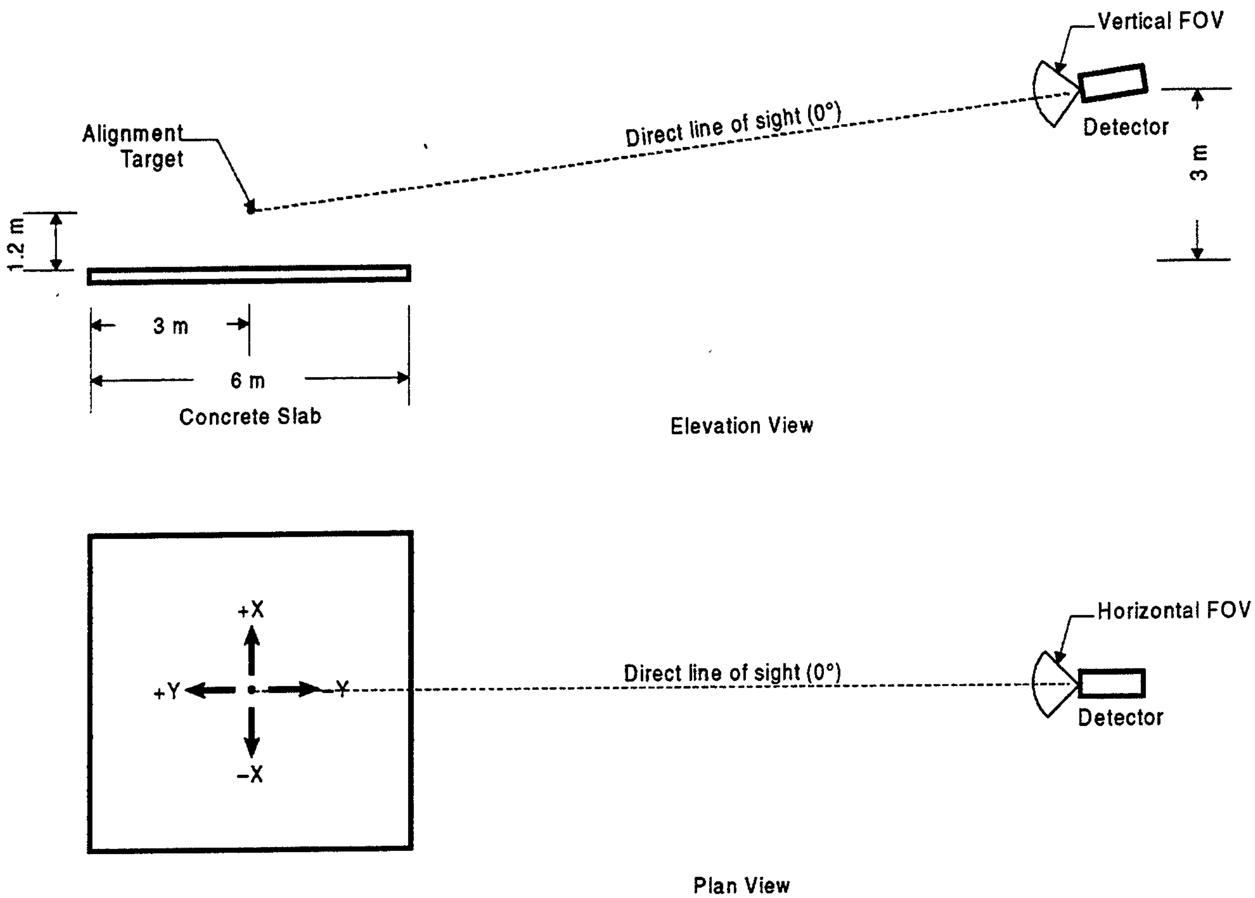


Fig. 1b – On-axis alignment of detection arrays 1 and 4 showing vertical field of view (FOV) and horizontal FOV

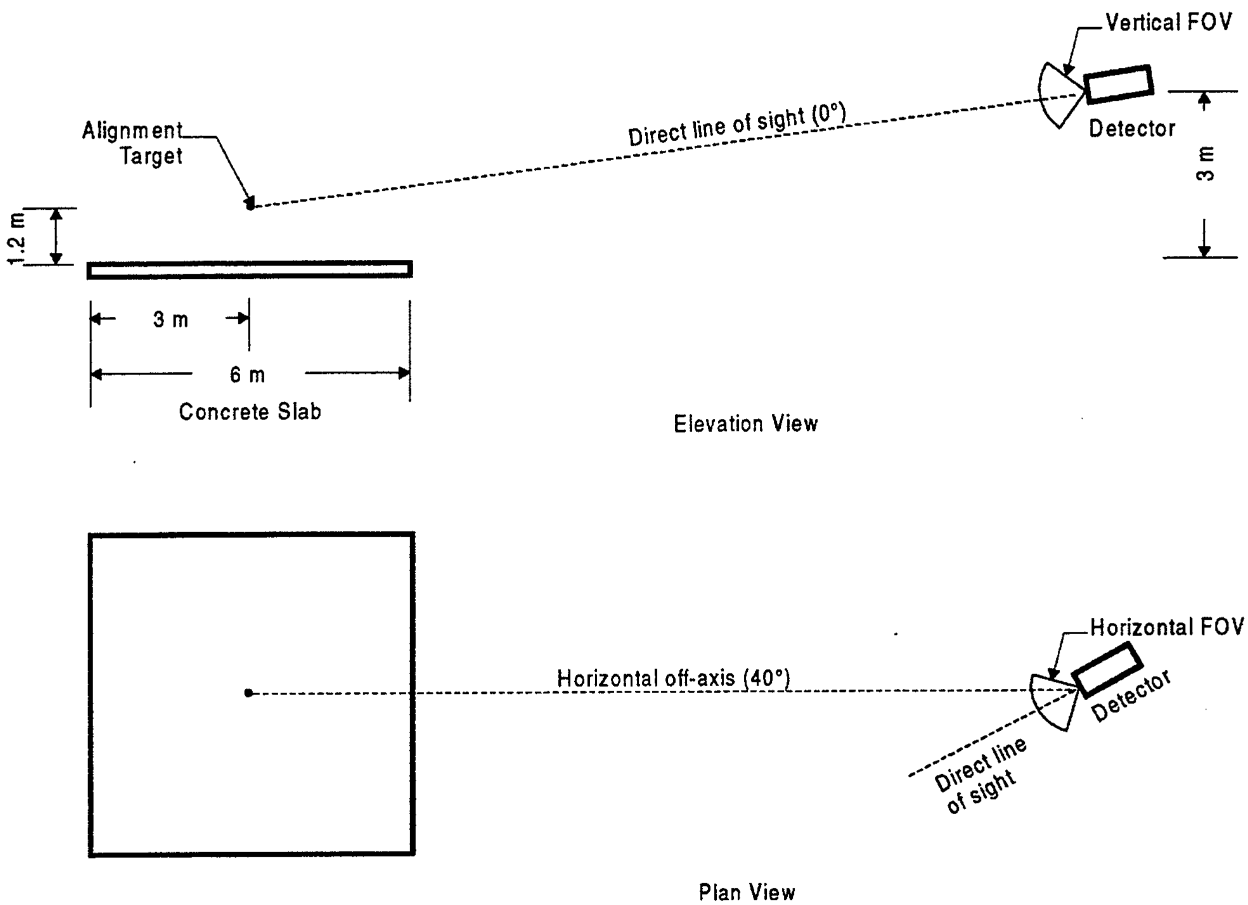


Fig. 1c – Horizontal off-axis alignment of detector arrays 2 and 5

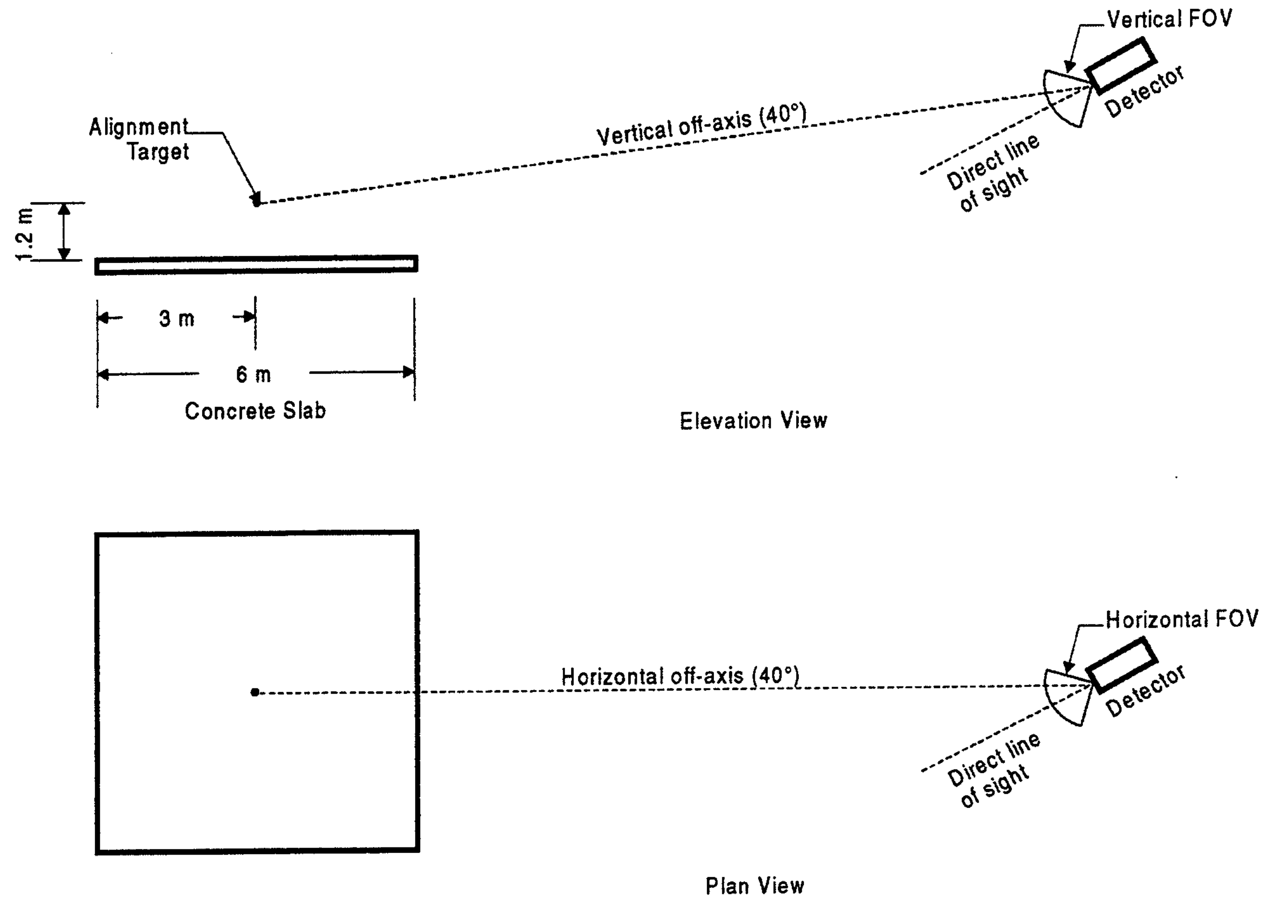


Fig. 1d – Horizontal and vertical off-axis alignment of detector arrays 3 and 6

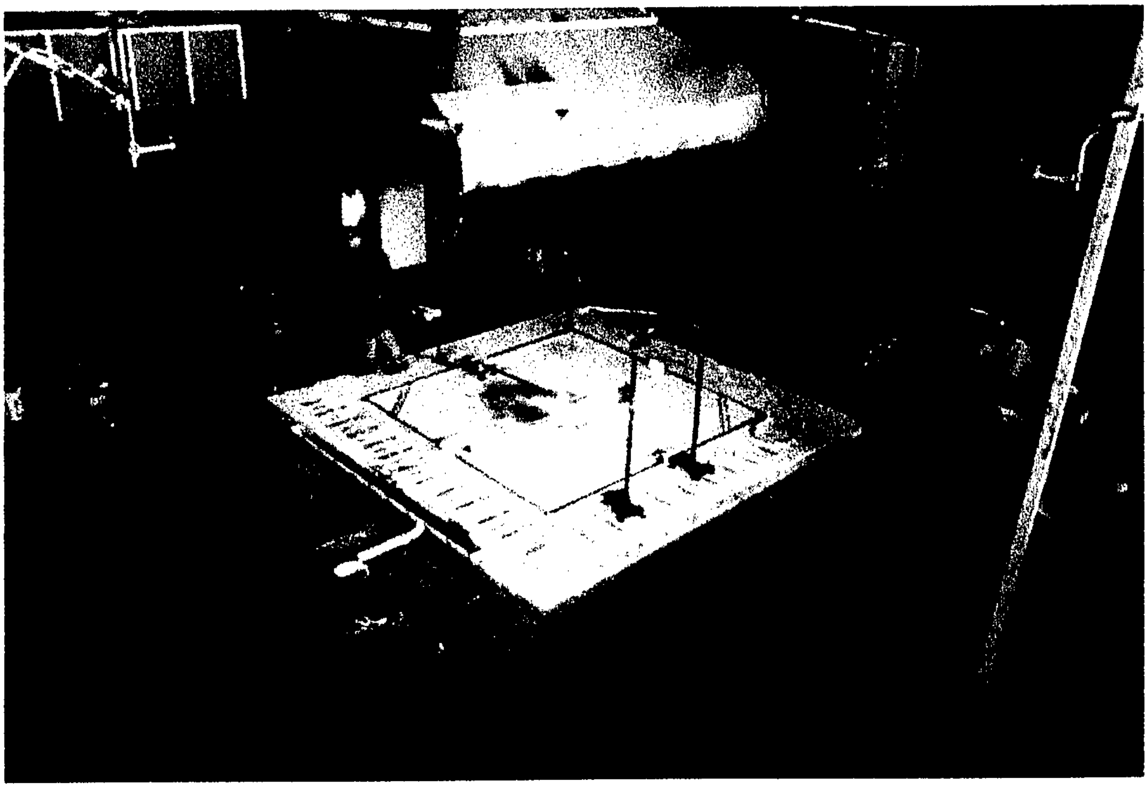


Fig. 2 – Overhead photograph of test area showing concrete pad, instrumented collection hood, black background (OFDs direct line of sight is approximately in-line with trench in left corner of photo)

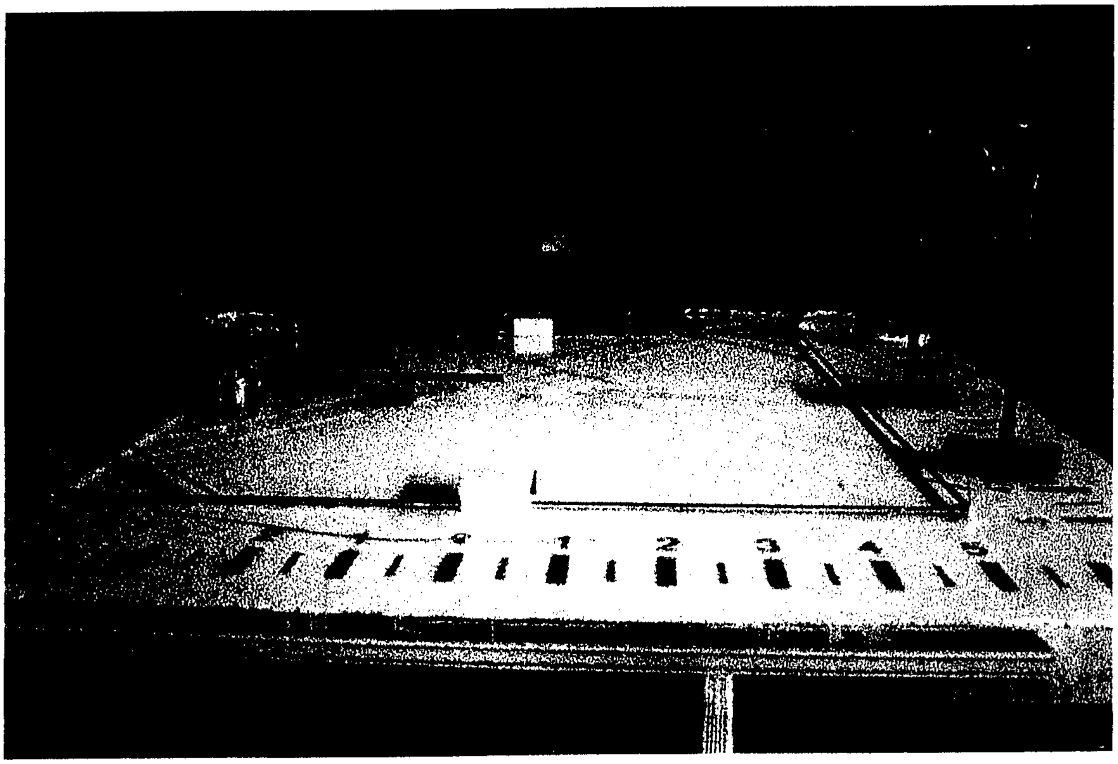


Fig. 3 – Photograph of concrete pad with continuously flowing fuel source (pipe) at center and instrumentation - x-direction is from left to right in the photograph. View is from the detectors

All fires were conducted under a 2.4 m by 4 m instrumented exhaust hood located 2.75 m above the concrete slab. The hood exhaust stream was instrumented to provide time resolved heat release rate measurements of the fires [8].

5.2 Test Fires

Based on a review of existing test protocols and published detection capabilities (i.e., manufacturers' literature), it was determined that test fires ranging in size from 100 kW to 1000 kW would be appropriate to test the capabilities of the detectors at 30 and 46 m distances. The Factory Mutual Standard 3260, "Flame Radiation Detectors for Automatic Fire Alarm Signaling," refers to the use of one or more of the following fires [9]:

- 0.093 m^2 (1 ft^2) heptane (~132 kW);
- 0.093 m^2 (1 ft^2) gasoline (~115 kW);
- 0.093 m^2 (1 ft^2) alcohol (~32 kW);
- 0.13 m (5 in.) propane flame from a 0.053 cm (0.021 in.) orifice; and
- 0.76 m (30 in.) natural gas flame from a 0.95 cm (0.375 in.) orifice.

Detector sensitivity is expressed as the maximum distance from the fire center at which the detector will give consistent alarm responses. The estimated heat release rates shown above for the FM tests were calculated using property data reported by Babrauskas for small size fires [10] and in reference [11]. A review of OFD promotional literature indicates that current detectors are able to detect the FM test fires at distances of approximately 15 m (50 ft) in 1 sec and up to 61 m (200 ft) in less than 10 seconds. Considering that the largest FM test fire is about 130 kW, using a range of fires from 100 to 1000 kW was considered appropriate to evaluate and bound the performance of current OFDs. In addition, this range of fires represent sizes that one would expect a detection system to detect.

Several spill fire scenarios were developed to evaluate the placement of the ignition source with respect to the spill, the aspect ratio (i.e. depth) of the fire in the view of the detector, and the partial obstruction of the fire to the view of the detector. In addition, several pan fires (i.e., fully contained and quiescent) were used to establish a comparative baseline with existing test methods. The four main types of fire scenarios that were evaluated are as follows:

a. An unconfined continuous spill at ground level with ignition at the source,
b. A continuous confined spill (i.e., channeled in one direction) at ground level with ignition at the source,
c. An unconfined fixed quantity spill with ignition after the pool was static, and
d. A pan fire.

Each fire type is explained in the following sections. These fire scenarios were initially developed during a series of tests conducted at the Naval Research Laboratory Chesapeake Beach Detachment facility [12].

5.2.1 Unconfined Continuous Spill Fire with Ignition at Source

This scenario (referred to as Unconfined Fire) represents the most general spill fire in which fuel was freely dispensed onto the concrete floor and allowed to spread radially. Figure 4 shows a schematic of the setup for the unconfined spill fire scenario with ignition at the source. The main fuel supply system consisted of a modified 22.7 L (6 gal) tank (Granger, stock no. 4F692) pressurized with nitrogen to 138 kPa (20 psig). The fuel was supplied from the pressurized fuel tank through 1.3 cm (0.5 in.) copper tubing with a transition to a 2.5 cm (1 in.) pipe which was 0.9 m (3 feet) long. The spill was created by flowing fuel from the open ended pipe.

Fuel flows were remotely controlled via a normally-closed solenoid valve and an in-line flowmeter. A Dwyer RMC-134 rotameter was used for nominal flow rates of 0.17, 0.42, and 0.85 Lpm (2.7, 6.7, and 13.5 gph) and a Dwyer RMC-142 rotameter was used for a nominal flow rate of 1.7 Lpm (27 gph). The flowmeters were calibrated by the manufacturer for water flows and the reported flowrates have not been corrected for the specific fuels. Therefore, actual flowrates may be 10 to 20 percent higher. However, the main purpose of the flowmeter was not to measure the flow but rather to maintain test to test repeatability. In addition to the flowmeter, continuous mass measurements of the pressurized fuel tank were taken to confirm the total volume of fuel flowed. The tank was placed on a counter balance scale which provided mass measurements with a maximum error of 0.1 g over a 22.7 kg (50 lb.) range.

Ignition at the source of the spill was obtained using a shielded acetylene torch flame. An acetylene flame approximately 25 cm long (10 in.) and 5 cm (2 in.) in diameter was shielded from the detectors by a piece of aluminum plate attached to the torch. The torch was positioned such that the flame was impinging on the concrete pad within 15 cm of the center of the spill. Preliminary tests demonstrated that the torch did not cause an alarm with any of the detectors.

5.2.2 Continuous Confined Spill Fire with Ignition at Source

In this scenario (referred to as Confined fire), a spill forms as a running line fire, i.e., fuel is channeled due to momentum of fuel flow and obstacles on the floor. This fire scenario represents a case when cabling or other obstacles in a hangar may channel fuel in a narrow spill geometry. Prior to testing it was not clear to what degree the depth of the fire affected OFD performance. By comparing the results of these confined spill fire tests to those of the unconfined spills, which were wider fires, a measure of the effect of flame geometry on OFD performance was obtained. The objective was to develop growing spill fires that have similar size (i.e., heat release rate) versus time profiles as those created in the unconfined scenarios. As discussed in Section 6.11, although growth curves (i.e., heat release rate per time) were different for equivalent flow rates, some comparisons could be made between confined and unconfined fires of different flow rates.

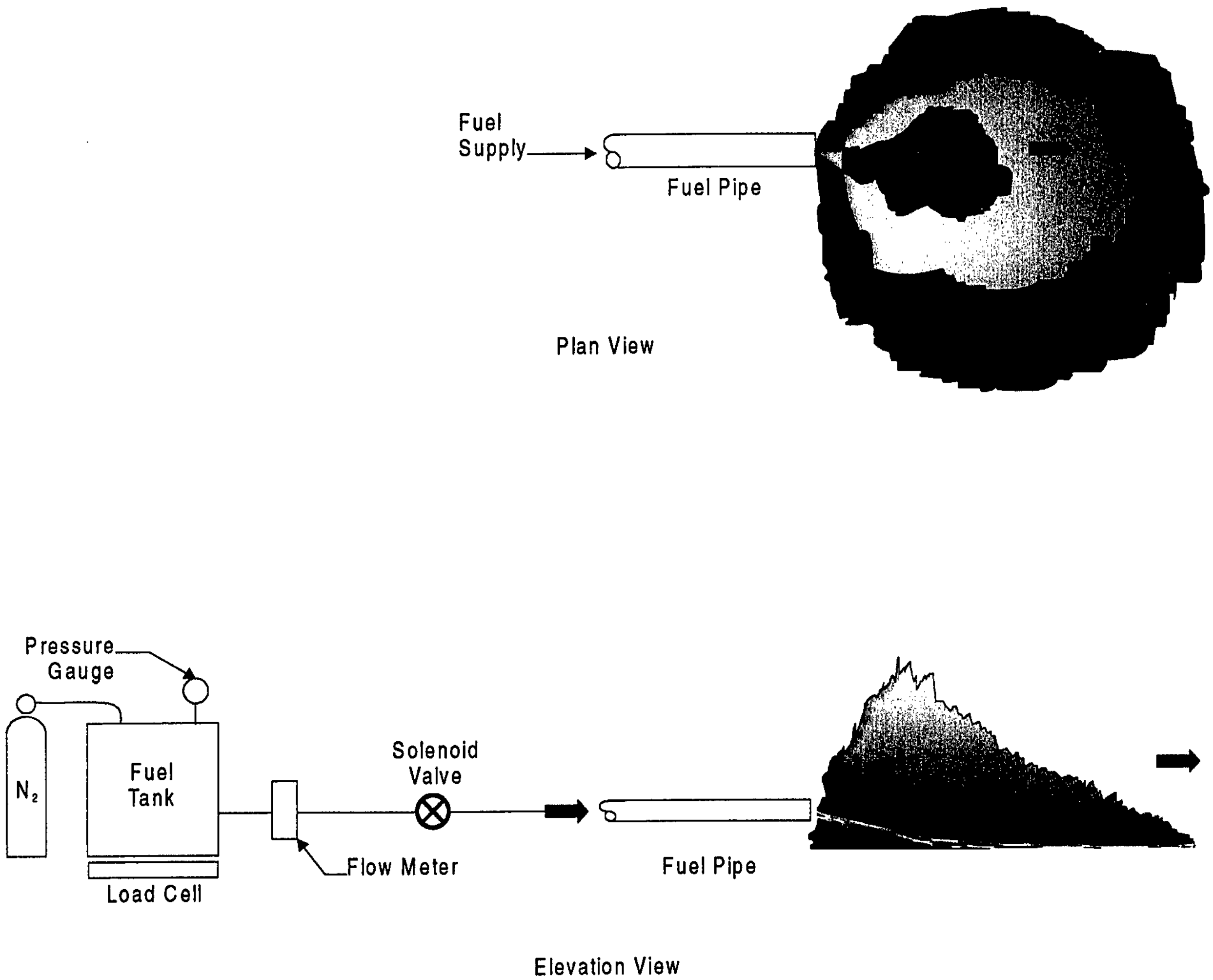


Fig. 4 – Experimental setup for unconfined spill fire scenarios with ignition at the source

Figure 5 shows a schematic of the confined spill fire scenario with ignition at the source. As shown, two pieces of 2.5 cm (1 in.) steel angle were anchored and sealed against the concrete floor to confine the spill to a 0.15 m (6 in.) channel flow. The fuel supply and ignition system were the same as described in Section 5.2.1.

Two sets of OFD tests were conducted with this scenario. The first set consisted of orienting the channel flow so that the fire spread perpendicularly with respect to the on-axis line of sight of the detectors (i.e., Confined X-direction fire scenario, see Figure 1b). The second set of tests consisted of orienting the channel directly in line with the on-axis line of sight of the detectors, such that the fire grew toward the detectors (i.e., Confined Y-direction fire scenario). The comparison of results between these different orientations was also to provide a measure of the effect of flame geometry on OFD performance.

5.2.3 Unconfined Fixed Quantity Spill Fire with Ignition After the Pool Is Static

This fire scenario (referred to as Fixed Quantity) consisted of spilling a fixed quantity of fuel on to the concrete slab. Once the spill become static (i.e., the area change became insignificant) the fuel was ignited on one edge using the shielded acetylene torch described in 5.2.1. The fuel was spilled from a height of 0.61 m (2 ft) using an axle mounted steel cylinder which was remotely operated to pivot and dump its contents (Figure 6). Three fixed quantity fuel spill scenarios were evaluated: 1, 2, and 3 L (0.26, 0.53 gal and 0.79 gal)

5.2.4 Pan Fire

This pool fire scenario consisted of burning fuel in a square pan or circular pan. This type of fire is currently used for most OFD performance evaluation testing [9]. These tests served as a representative benchmark to compare the spill fire test results. Tests were conducted by filling a pan with a fixed quantity of fuel on top of 2.5 cm of water. The fuel was ignited in the center of the pan with the shielded acetylene torch described in 5.2.1. Three different pan sizes were used: 1) 0.3 x 0.3 m (1 x 1 ft) square, 0.10 m (4 in.) deep, 2) 0.61 x 0.61 m (2 x 2 ft) square, 0.15 m (6 in.) deep, and 3) 0.91 m diameter, 0.10 m (4 in.) deep.

5.3 Fuel

Three fuels were evaluated during this test series, JP-8, JP-5 and gasoline. Since JP-8 represents the more easily ignited fuel (compared to JP-5) of the fuels used by the Navy, most tests utilized this fuel. To assess the effect of fuel dependence on OFD performance, a limited number of tests were conducted with JP-5. Gasoline was used only with pan fires as it is commonly used in this manner for OFD performance tests. Table 1 contains fuel property data, where Δh_c is the net heat of combustion of the fuel.

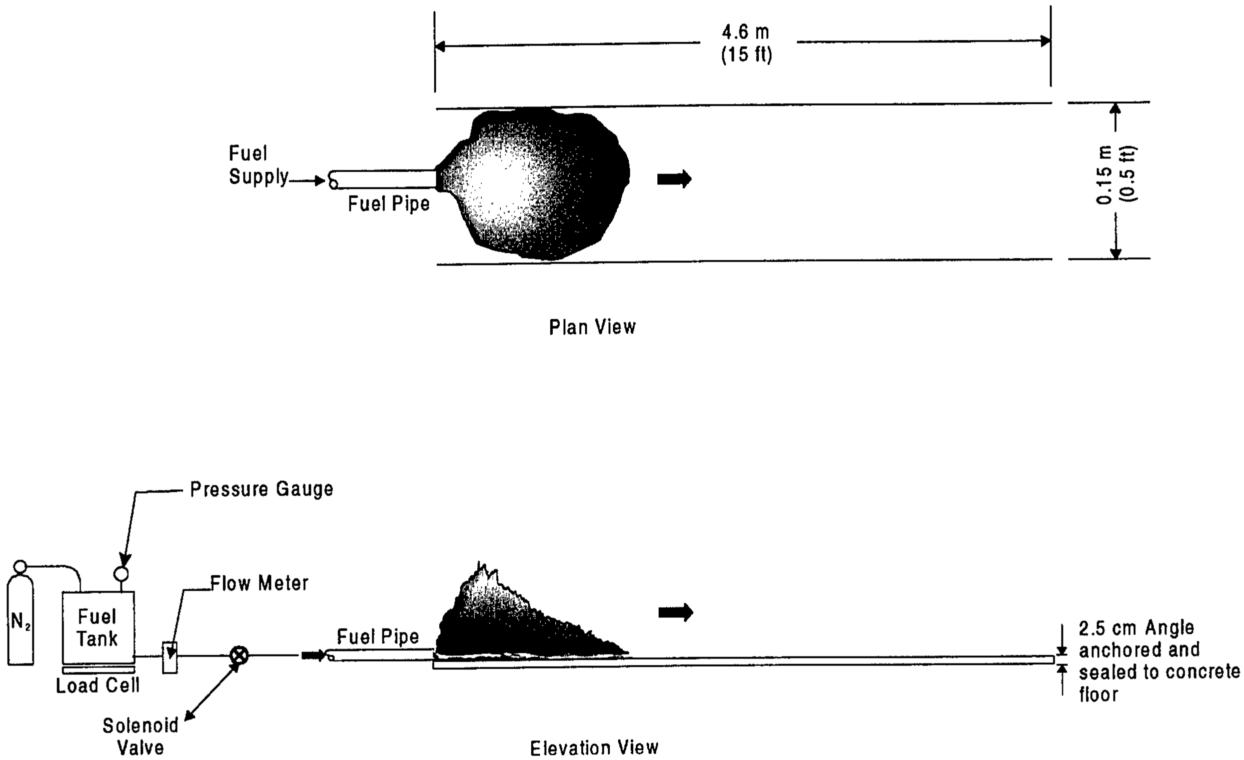


Fig. 5 – Experimental setup for confined spill fire scenarios with ignition at the source

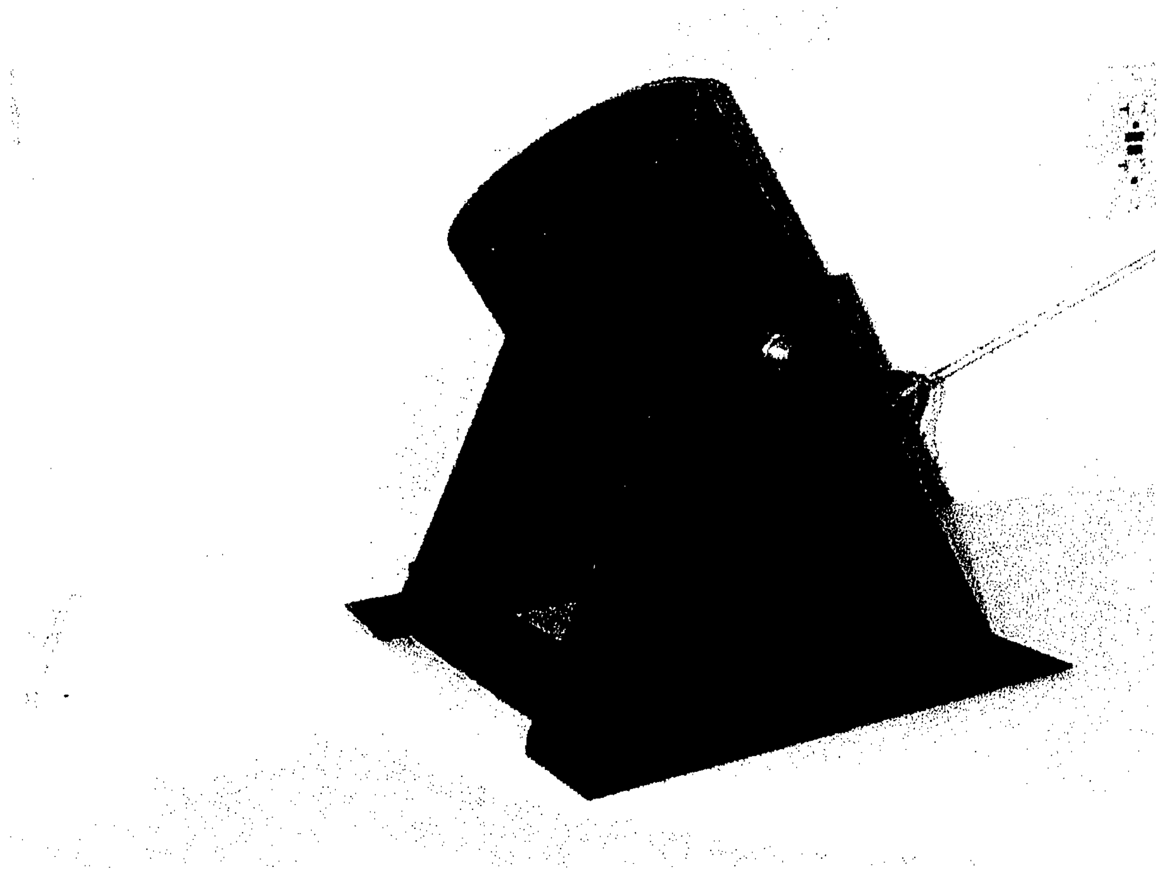


Fig. 6 – Photograph of pivoting, axle-mounted steel cylinder

Table 1. Fuel Properties

Fuel	Flash Point (C (F))	Δh_c (kJ/kg)	Density (kg/m^3)
JP-5	62 (144)[1]	43000[2]	791[1]
JP-8	52 (126)[1]	43200[2]	807[1]
Gasoline	-43 (-45)[3]	44000[4]	729[1]

1 Measured value
2 Reference [11]
3 NFPA 325
4 SFPE Handbook

5.4 OFD Test Scenarios

Besides the various fire scenarios described in Section 5.2, the optical fire detectors were exposed to fires in combination with different, potential nuisance sources and obstructions within the field of view of the detectors. The scenarios were designed to be representative of plausible sources that could occur in hangars. Table 2 lists the different OFD exposure scenarios evaluated. The details of each scenario are discussed in the following sections. In some cases, inclusion of potential nuisance sources within a detectors field of view can impede or prevent the detector from identifying an alarm condition with a real fire.

Table 2. Optical Fire Detector Test Scenarios

Scenario No.	Description	Fuel Flow Rate / Amount Spilled
1	**Unconfined**	0.17, 0.42, 0.85, and 1.7 LPM
2	with chopped UV/IR	0.17 and 1.7 LPM
3	with chopped IR at 20 m	0.17 and 1.7 LPM
4	with chopped IR at 26 m	0.17 and 1.7 LPM
5	with obstruction 0-1.34 m ht	1.7 LPM
6	with moving obstruction 0-1.34 m ht	1.7 LPM
7	with obstruction 0.3-2.3 m ht	0.42 and 1.7 LPM
8	with moving obstruction 0.3-2.3 m ht	0.42 and 1.7 LPM
9	with arc welding at 15 m	0.17 and 1.7 LPM
10	with arc welding at 27 m	1.7 LPM
11	with doors open and lights on	0.17 and 1.7 LPM
12	**Fixed Quantity**	1, 2, and 3 L
13	**Confined** (x-dir)	0.17, 0.42, and 0.85 LPM
14	**Confined** (y-dir)	0.17, 0.42, 0.85, and 1.7 LPM
15	with chopped UV/IR	0.17 and 0.85 LPM
16	with chopped IR @20 m	0.17 and 0.85 LPM
17	with chopped IR @26 m	0.17 and 0.85 LPM
18	**Pan**	0.3 x 0.3 m, 0.6 x 0.6 m, and 0.91 m dia.

5.4.1 Chopped UV/IR Source

Figures 7 and 8 show photographs of the apparatus used to produce a chopped UV/IR signal. The chopped UV/IR source consisted of a set of three, 500 W halogen work lamps with the glass covers removed. Chopping was achieved by rotating a segmented drum around the axis of the row of lamps positioned horizontal to the ground. The chopping frequency was 4.7 Hz. The lamps were angled to face directly at the detectors located at 31 m from the pad center. The chopped UV/IR source was positioned at 20 m from the pad center (i.e., 11 m and 26 m from the two detector masts).

5.4.2 Chopped IR Source

Figure 9 shows a photograph of the apparatus used to produce a chopped IR signal within the detector field of view. The IR source consisted of a 1500 W quartz heater (Windmere, Model 4396DB) which was mounted horizontally in the same rotating, segmented drum used with the UV/IR source. The chopping frequency was 4.7 Hz. Tests were conducted with the chopped IR source located at 20 and also 26 m from the center of the concrete pad in line with the detectors.

5.4.3 Obstructions

Two obstructions were used with the unconfined spill fire scenarios. The first obstruction consisted of a 2.4 m long, black board which was positioned at the front edge of the concrete pad and extended from the pad up to a height of 1.34 m. Figure 10 shows a photograph of the 0-1.34 m high obstruction in front of an unconfined spill fire 0.3 m to 2.25 m. The board represented an obstruction which may occur in a hangar, such as tool carts, load pallets, trucks or other aircraft.

The second obstruction was a 2.4 m long, black board which was positioned at the front edge of the concrete pad from a height of 0.3 m to 2.25 m. Figure 11 shows a photograph of the 0.3 to 2.3 m obstruction in front of an unconfined spill fire. With this raised obstruction, the bottom portion of the flame is in the detectors field of view. This scenario represents the case that the fire is obstructed above by an aircraft. Because soot formation generally occurs higher in flame, the radiation from the base of the fire can vary from that at the top. These obstruction tests provided information for assessing whether the different detection technologies preferentially perform better when viewing different regions of the fire plume.

Additional obstruction tests were conducted in which the obstruction was rapidly moved out of the line-of-sight of the detectors (moved within 2 seconds). The obstruction was moved 60 seconds after the ignition of the fire. At this time the spill was fully involved in flame and the heat release rate was at the steady-state value.

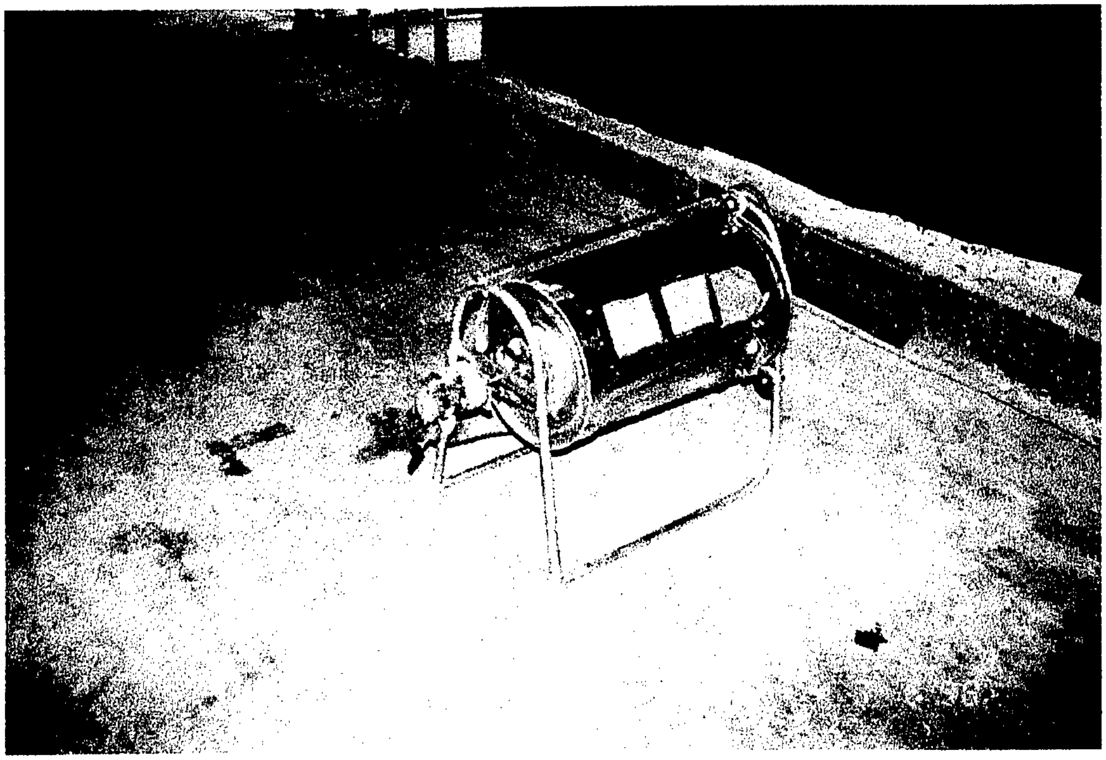


Fig. 7 – Photograph of chopped UV/IR source, three halogen lamps inside rotating segmented drum

Fig. 8 – Close-up photograph of chopped UV/IR source showing halogen lamps with glass covers removed

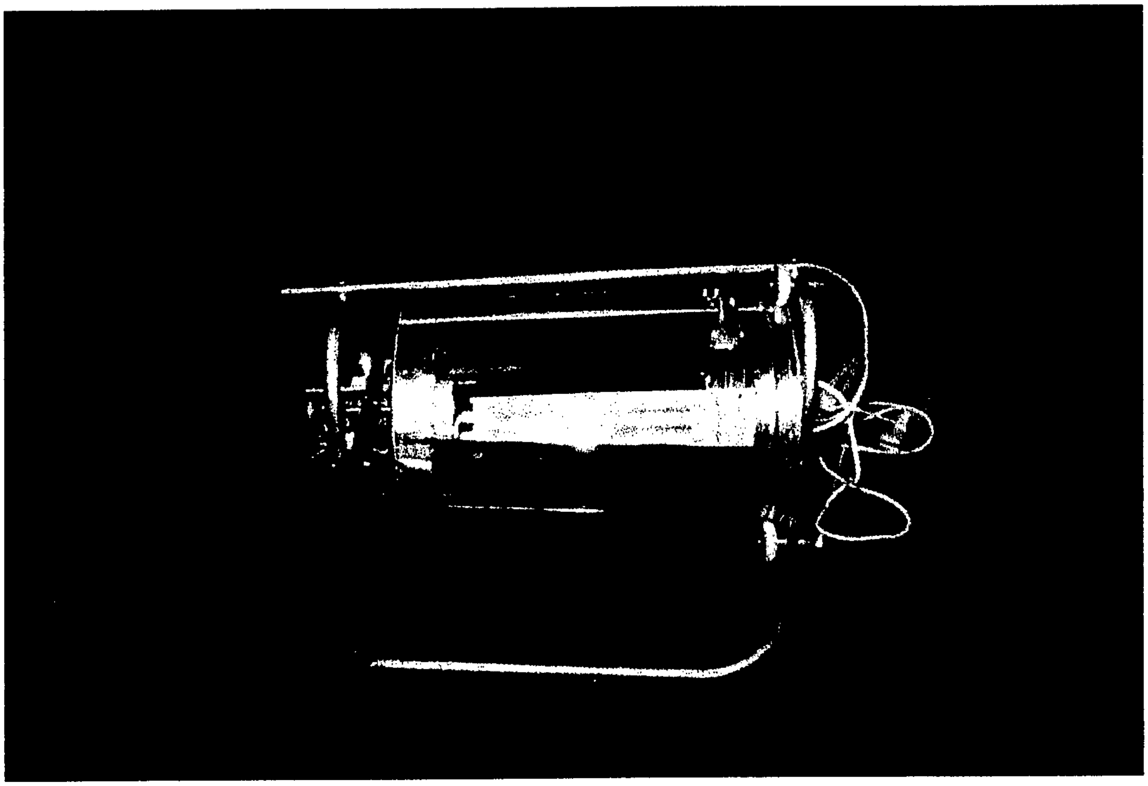


Fig. 9 – Photograph of chopped IR source, a quartz heater inside a rotating, segmented drum

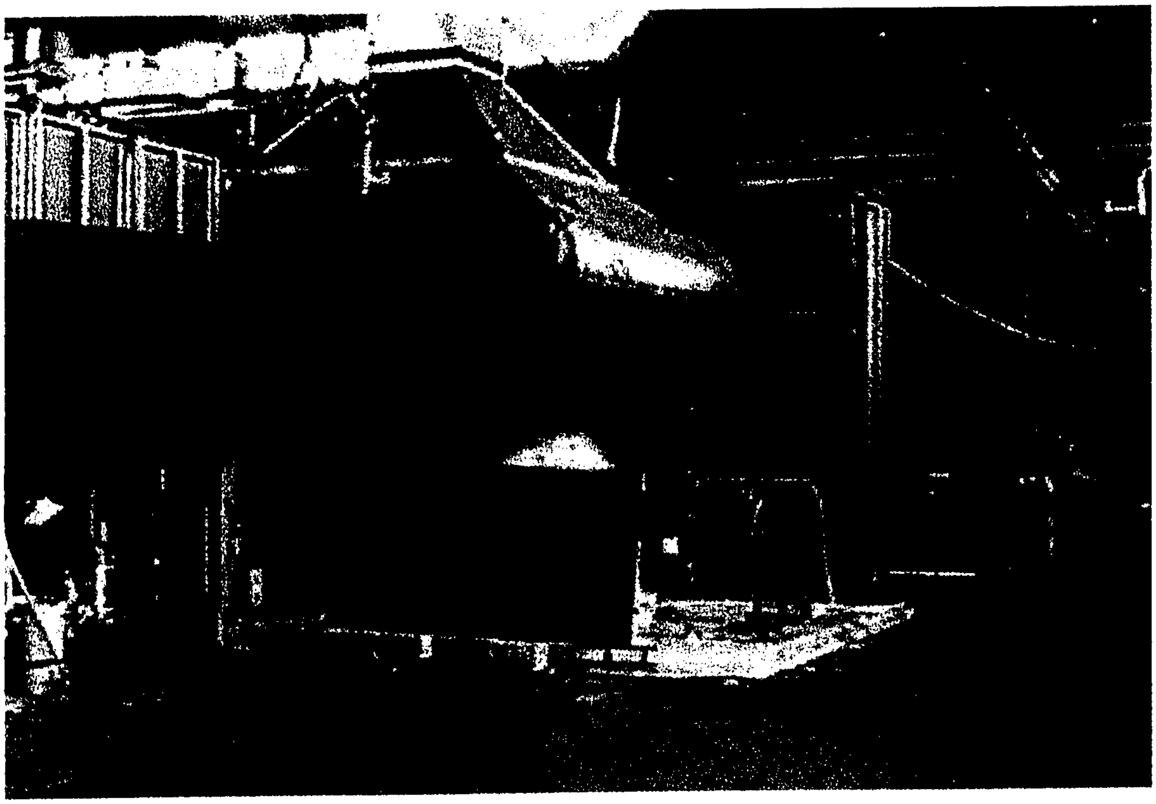


Fig. 10 – Photograph of the 0-1.34 m obstruction in front of an unconfined spill fire (Test 52, ~1000 kW)

Fig. 11 – Photograph of the 0.3 to 2.3 m obstruction in front of an unconfined spill fire (Test 59, ~1000 kW)

5.4.4 Arc Welding

The arc welding event consisted of a man using an arc welder set to 100A and a 6013, 0.318 cm (1/8 in.) organic binder rod along a piece of steel set on the floor. During the test, two welding rods were used in succession with a 15 to 18 second down time in between changing the rods. Welding was begun at 50 seconds into the test, which was 10 seconds before the fire was initiated. The second rod was consumed by 130 to 145 seconds. The welding setup was located at either 15 or 27 m from the center of the concrete pad and in line with the detectors. The welder was positioned to the side of the steel such that he did not obstruct the detectors view of the welding or the fire.

5.4.5 Doors Open and Lights On

These tests were conducted to determine if additional light into the building had an effect on detector performance. During these tests, five 3.5 m wide, 4.27 m high roll up doors were opened along the perimeter of the test building. Additionally, ten 240 V, 1500 W quartz halogen lights were turned on. The lights were located on the west wall of the building (the -X direction with respect to the concrete slab and OFDs) 6 m above the floor. Opening the doors allowed additional bright sun light into the building.

5.5 Optical Fire Detectors

Six optical fire detector models (OFD) were evaluated in this test program. Table 3 summarizes the detector test designations, model type, and test position and orientation. Each OFD model tested was designated OFD1 through OFD6. The letters A through F designate the location and orientation of the detector. Of the six detector models, three were UV/IR (OFD1, 2 and 5). One was a dual IR (2-IR, OFD4), and two were triple IR (3-IR, OFD3 and 6). In total there were 36 detectors tested (6 models in 6 different orientations).

The layout and orientation of the detectors was presented in Section 5.1, General Setup, and in Figures 1a-1d. The detectors were aligned using a laser sight (Det Tronics) at the detector and a target 1.2 m above the center of the concrete pad. The laser sight was mounted in a plastic holder which fit either around or up against the detector. The holder was pre-drilled with holes to align the laser for direct line of sight (DLS) and 40 degrees off axis. The holder with the laser in the 40 degree position was rotated about the DLS axis to yield both the horizontal off-axis (HOA) and the horizontal and vertical off-axis (HVOA).

All of the detectors were set according to the manufacturers recommended settings for the 31 m and 46 m locations as would be recommended for Navy hangar use. At each location, all detectors of the same model were set identically. The OFDs were set in a non-latching mode, such that the unit would return to normal operation after the alarm source (the fire) was removed or reduced below the alarm threshold.

Table 3. Summary of Optical Fire Detector Designations and Test Locations

Detector Designation	Description	Location and Orientation
OFD1A	UV/IR	30.5 m Direct line of sight
OFD2A	UV/IR	30.5 m Direct line of sight
OFD3A	Triple IR	30.5 m Direct line of sight
OFD4A	Dual IR	30.5 m Direct line of sight
OFD5A	UV/IR	30.5 m Direct line of sight
OFD6A	Triple IR	30.5 m Direct line of sight
OFD1B	UV/IR	30.5 m Horizontal off-axis
OFD2B	UV/IR	30.5 m Horizontal off-axis
OFD3B	Triple IR	30.5 m Horizontal off-axis
OFD4B	Dual IR	30.5 m Horizontal off-axis
OFD5B	UV/IR	30.5 m Horizontal off-axis
OFD6B	Triple IR	30.5 m Horizontal off-axis
OFD1C	UV/IR	30.5 m Horizontal and vertical off-axis
OFD2C	UV/IR	30.5 m Horizontal and vertical off-axis
OFD3C	Triple IR	30.5 m Horizontal and vertical off-axis
OFD4C	Dual IR	30.5 m Horizontal and vertical off-axis
OFD5C	UV/IR	30.5 m Horizontal and vertical off-axis
OFD6C	Triple IR	30.5 m Horizontal and vertical off-axis
OFD1D	UV/IR	45.8 m Direct line of sight
OFD2D	UV/IR	45.8 m Direct line of sight
OFD3D	Triple IR	45.8 m Direct line of sight
OFD4D	Dual IR	45.8 m Direct line of sight
OFD5D	UV/IR	45.8 m Direct line of sight
OFD6D	Triple IR	45.8 m Direct line of sight
OFD1E	UV/IR	45.8 m Horizontal off-axis
OFD2E	UV/IR	45.8 m Horizontal off-axis
OFD3E	Triple IR	45.8 m Horizontal off-axis
OFD4E	Dual IR	45.8 m Horizontal off-axis
OFD5E	UV/IR	45.8 m Horizontal off-axis
OFD6E	Triple IR	45.8 m Horizontal off-axis
OFD1F	UV/IR	45.8 m Horizontal and vertical off-axis
OFD2F	UV/IR	45.8 m Horizontal and vertical off-axis
OFD3F	Triple IR	45.8 m Horizontal and vertical off-axis
OFD4F	Dual IR	45.8 m Horizontal and vertical off-axis
OFD5F	UV/IR	45.8 m Horizontal and vertical off-axis
OFD6F	Triple IR	45.8 m Horizontal and vertical off-axis

5.6 Instrumentation

Instrumentation in this test program included the optical fire detectors (which were provided by the manufacturers), transducers for heat flux measurements, thermocouples for temperature measurements, flowmeters for fuel flow rate monitoring, detectors for visible and infrared (IR) radiation, and video and still photography. Appendix A includes the instrumentation list used for this test series. Figure 12 shows a schematic of the instrumentation plan for the spill fire test area on the concrete slab. Figure 2 shows a photograph of the slab with instrumentation.

5.6.1 Concrete Slab Temperature

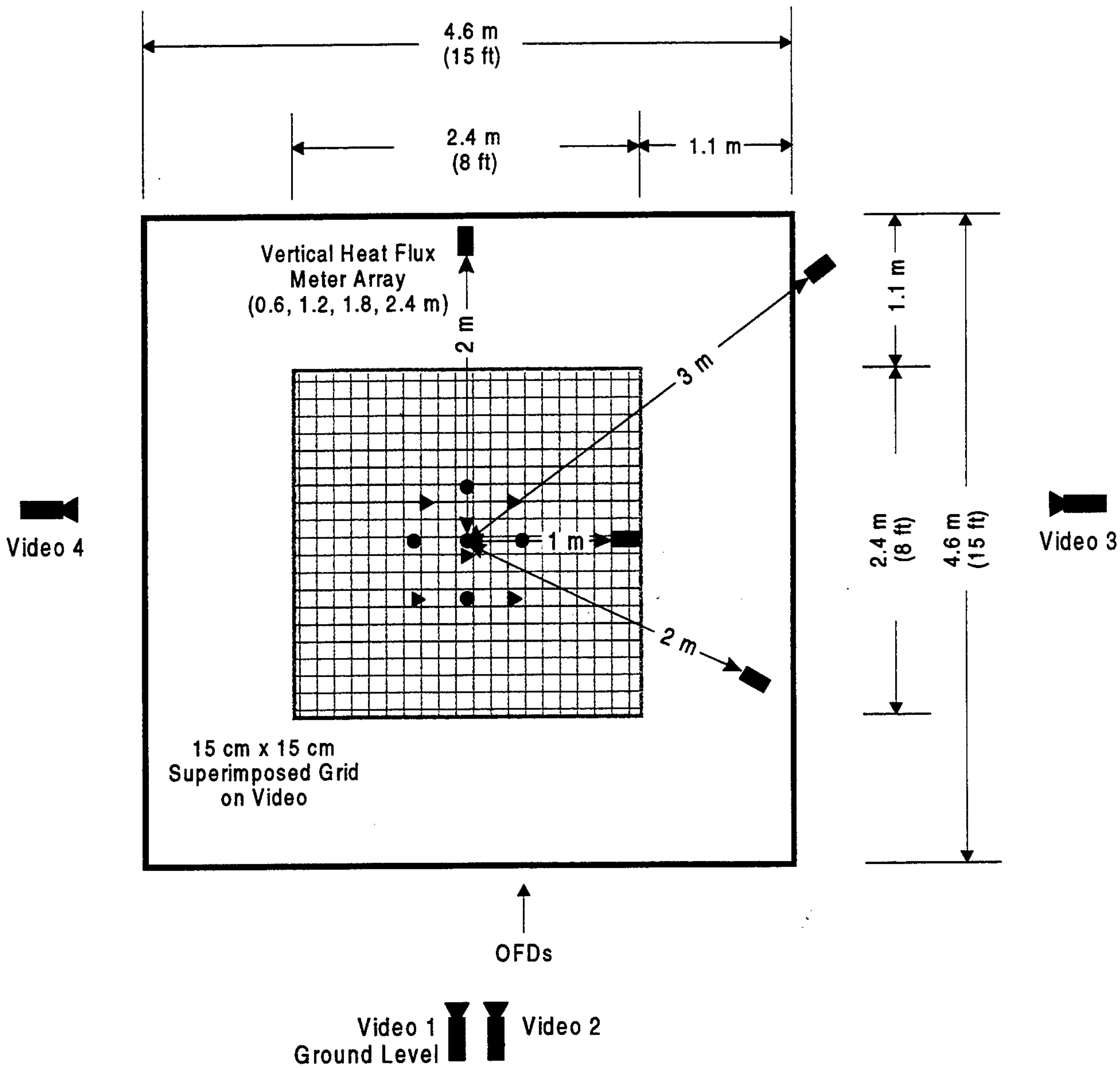
The concrete slab temperature was measured with thermocouples placed on the surface and within the slab. The in-slab temperatures were measured with five Type K, 0.16 cm diameter (1/16 in.) stainless steel sheathed, closed head grounded thermocouples. The thermocouples were imbedded in the concrete slab as it was poured. The thermocouples were within 0.6 cm from the top surface. As shown in Figure 12, the five in-slab temperature measurements consisted of one at the slab center and one along each axis, 0.5 m radially from the center.

The slab surface temperature was measured with five Type K, 0.16 cm diameter (1/16 in.) stainless steel sheathed, closed head grounded thermocouples. These thermocouples were placed under tension against the top surface of the concrete slab using a wire bow arrangement as seen in Figure 2. The wires supporting the thermocouples were stretched from corner to corner on a rigid square frame made of conduit. As shown in Figure 12, the surface thermocouples were positioned similarly to the in-slab thermocouples except they were rotated 45 degrees about the slab center. Type K thermocouples (0.32 cm (0.125 in.)) were also used to monitor the fuel temperature in the main supply cylinder.

5.6.2 Fire Size

In general, different size growth rate spill fires were created by varying the fuel flow rate or the fixed quantity spilled. Given the state of the knowledge of spill fires, it was not possible to accurately predict the resulting spill size and fire size at the different fuel flow rates. This was particularly true for the transient growth period. Little data exists that can be used to determine the typical thickness or pool area that will occur for a fuel spill. In addition, it was not clear how to quantitatively characterize the burning rate of a quiescent spilled fuel fire with thin pool depths; obviously, transient spill fires are even more difficult.

The primary means of measuring the fire size was via oxygen calorimetry with the instrumented hood that collected the fire effluent. Operation of the hood had minor to no effect on the fires. In addition to these measurements, the physical fire size was also measured by three other means: 1) on-site visual observation with the aid of graduated markers both on the concrete



● Thermocouple imbedded in concrete (0.5 m from slab center)

▲ Thermocouple against top surface of concrete pad (0.5 m from slab center)

■ Heat flux meter, 1.2m above slab (unless noted on drawing); # designates distance from slab center

Fig. 12 – Instrumentation plan for spill fire test area on concrete slab

floor and vertically near the fire, 2) visual size measurements from video records with a superimposed grid, and 3) the use of Ni-Chrome ribbon wire. The on-site measurements were made by two observers, one positioned to view the fire from the -Y direction and one from the + X direction (see Figure 1b). The observers used the graduation markers on the concrete to estimate the spill fire size every 10 seconds after fire initiation (see Figure 2 for markers). Both continuous and intermittent flame heights were recorded using vertical markers. The graduation markers on the concrete were spaced 15 cm (6 in.) apart.

Four video cameras were used to record each test. The layout of the video cameras is shown in Figure 12. Camera 1 was located about 1.2 m above the ground to record the vertical structure of the fire. A wire screen with 1.27 cm (0.50 in.) square spacing was positioned in front of the video camera so that a grid was superimposed on the video of the fire. The setup was calibrated to yield a grid with 30.5 cm (1 ft) spacings at the center of the concrete slab.

Cameras 2, 3 and 4 were elevated to view down on the concrete slab at three different orientations. A grid was superimposed onto the videos from Cameras 2 and 3. Due to physical restrictions, Camera 4 could not be elevated high enough that an effective overhead view of the slab could be obtained. The grid superimposed on the overhead views was graduated in 0.15 cm (6 in.) increments over a 2.4 m x 2.4 m (8 x 8 ft) area centered on the concrete slab.

The last method of determining fire size was a novel setup using Ni-Chrome ribbon wire to measure the size of the burning spill. The Ni-Chrome wire method is discussed in reference [13], which is attached as Appendix B. This technique is based on the principle that the electrical resistance of the Ni-Chrome wire increases when heated. The change in resistance is proportional to the wire length which is directly exposed to the flame. In this test program, two wires were used to measure the X and Y direction fire dimensions. The wires were supported by (but electrically isolated from) the square conduit frame shown in the photographs of Figures 2 and 3, and corresponded to the X and Y axes, bisecting at the center of the concrete slab.

5.6.3 Targets for Thermal Radiation Measurements

Heat flux measurements were made with water-cooled, 0-20 and 0-50 kW/m^2 total heat flux gauges (Medtherm). As seen in Figure 12, the heat flux transducers were positioned 1, 2, and 3 m (3.3, 6.6, and 9.8 ft) radially away from the slab center at a height of 1.2 m (4 ft), which was determined to be a reasonable target height for Navy aircraft. A second array of heat flux transducers was positioned 2 m (6.6 ft) away from the fire at heights of 0.6, 1.2, 1.8, and 2.4 m (2, 4, 6, 8 ft). All gauges were 20 kW/m^2 except the one at 1 m away, 1.2 m high and the one at 2 m away, 0.6 m high. The two exceptions were the 0-50 kW/m^2 gauges. The heat flux measurements were obtained in support of the heat transfer model developed to assess the collateral damage to aircraft adjacent to a spill fire (Section 7).

In addition to the heat flux measurements, square aluminum plates (15 x 15 cm) were used as targets to represent segments of aircraft exposed to the spill fires. The aluminum plates

were placed at selected locations adjacent to the heat flux meters. The locations are identified in the instrumentation list in Appendix A. The samples consisted of 2024-T3 aluminum, either 1600 micron or 813 micron (0.063 and 0.032 in.) thick. These thickness are representative of aircraft skin thicknesses. The measured densities of the aluminum samples were 2860 and 2510 kg/m^3 (178.5 and 156.7 lb/ft^3), respectively. Front and back surface temperatures were measured at the center of each sample using type K, bear bead 30 gauge thermocouples. The thermocouple wires were attached to the aluminum plate with a plastic bolt, approximately 2.5 cm from the bead. The bead was then pressed against the plate under the tension of the wire and secured with a drop of EG&G thermal joint compound (Type 120). Figure 13 shows a photograph of the aluminum plate setup with thermocouples mounted adjacent to a heat flux meter.

5.7 Data Acquisition

All instrumentation output, including the optical fire detector alarms, warnings and faults, was logged at 1 second intervals by the data acquisition system (Solatron IMP system by Schlumberger Technologies with Micro Specialty Systems Inc. software). This data acquisition system was synchronized with the timers on the video records.

5.8 Test Procedure

The general test procedure was to check the OFDs before each test, start the data acquisition and video recorders, then ignite the fire. The OFDs were checked at the beginning of each day by exposing them to a 0.6 m diameter heptane pan fire positioned 9 to 19 m from the detectors. These tests were to confirm that the detectors produced an alarm value when exposed to a fire. Prior to each test, every OFD was checked to assure that it was indicating normal operation. The data acquisition system was started 60 seconds prior to initiating the fire.

After ignition of the fuel spill, the spill fire tests ran for less than three minutes (except for the pan fires). The unconfined spill fire tests were terminated by shutting off the fuel flow after the peak fire size (i.e., steady-state conditions) was achieved. Termination of these tests was also dependent on limiting the heating of the concrete pad to avoid spalling. As the fuel flow was shut off, the fire was manually extinguished with AFFF. For the fixed quantity spill fire tests, the fuel was allowed to completely burn and no extinguishment efforts were taken.

6.0 TEST RESULTS

One hundred and eighteen tests were conducted according to the fire and optical exposure scenarios discussed in sections 5.2 and 5.4. Table 4 presents a summary of the tests conducted. The table is arranged by test number which corresponds to the chronological order that the tests were conducted. Also identified in the table is the fuel used, the fire scenario, the fuel flow/amount spilled and the test conditions (i.e., the OFD exposure scenarios). Table 5 presents

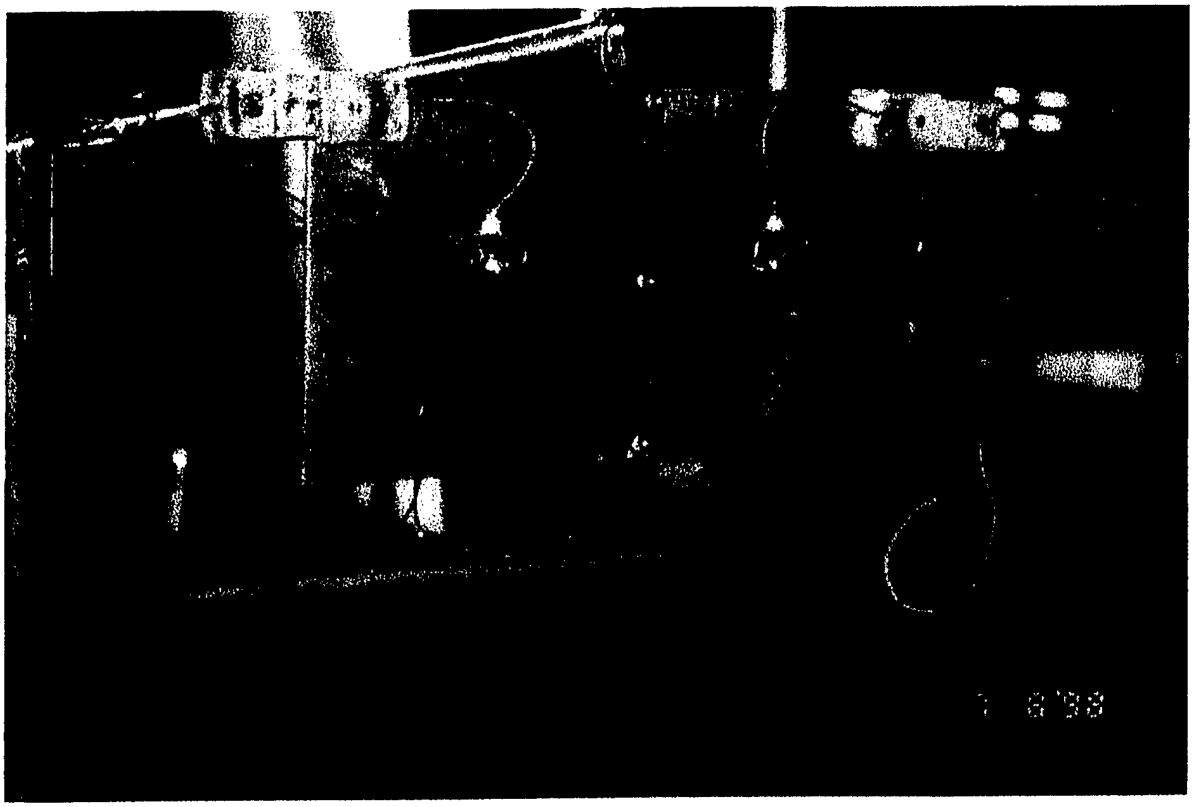


Fig. 13 – Photograph of two aluminum plates with mounted thermocouples and adjacent heat flux transducer (mounted in the end of the tube that can be seen above the two plates)

Table 4. Summary of Optical Fire Detector Tests

Test No.	Fuel	Fire	Fuel Flow/Amount	Test Scenario # and Conditions
1	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	1
2	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	1
3	JP-8	Unconfined spill	0.423 Lpm (6.7 gph)	1
4	JP-8	Unconfined spill	0.423 Lpm (6.7 gph)	1
5	JP-8	Unconfined spill	0.852 Lpm (13.5 gph)	1
6	JP-8	Unconfined spill	0.852 Lpm (13.5 gph)	1
7	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	1
8	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	1
9	JP-8	Fixed quantity spill	1 L	12
10	JP-8	Fixed quantity spill	2 L	12
11	JP-8	Fixed quantity spill	2 L	12
12	JP-8	Fixed quantity spill	3 L	12
13	JP-8	Pan fire (0.61 x 0.61 m)	7 L	18
14	Gasoline	Pan fire (0.61 x 0.61 m)	7 L	21
15	JP-8	Pan fire (0.91 m dia.)	13 L	18
16	Gasoline	Pan fire (0.91 m dia.)	10 L	21
17	JP-8	Confined spill (x-dir)	0.17 Lpm (2.7 gph)	13 - Perpendicular to line of sight
18	JP-8	Confined spill (x-dir)	0.17 Lpm (2.7 gph)	13 - Perpendicular to line of sight
19	JP-8	Confined spill (x-dir)	0.423 Lpm (6.7 gph)	13 - Perpendicular to line of sight
20	JP-8	Confined spill (x-dir)	0.423 Lpm (6.7 gph)	13 - Perpendicular to line of sight
21	JP-8	Confined spill (x-dir)	0.852 Lpm (13.5 gph)	13 - Perpendicular to line of sight
22	JP-8	Confined spill (x-dir)	0.852 Lpm (13.5 gph)	13 - Perpendicular to line of sight
23	JP-8	Confined spill (x-dir)	0.852 Lpm (13.5 gph)	13 - Perpendicular to line of sight
24	JP-8	Confined spill (x-dir)	0.423 Lpm (6.7 gph)	13 - Perpendicular to line of sight
25	JP-8	Confined spill (x-dir)	0.423 Lpm (6.7 gph)	13 - Perpendicular to line of sight
26	JP-8	Confined spill (y-dir)	0.17 Lpm (2.7 gph)	14 - Perpendicular to line of sight
27	JP-8	Confined spill (y-dir)	0.423 Lpm (6.7 gph)	14 - Parallel to line of sight

Table 4. Summary of Optical Fire Detector Tests (Continued)

Test No.	Fuel	Fire	Fuel Flow/Amount	Test Scenario # and Conditions
28	JP-8	Confined spill (y-dir)	0.852 Lpm (13.5 gph)	14 - Parallel to line of sight
29	JP-8	Confined spill (y-dir)	0.852 Lpm (13.5 gph)	14 - Parallel to line of sight
30	JP-8	Confined spill (y-dir)	0.17 Lpm (2.7 gph)	14 - Parallel to line of sight
31	JP-8	Confined spill (y-dir)	0.852 Lpm (13.5 gph)	15 - Chopped UV/IR (halogen lamp) at 20 m
32	JP-8	Confined spill (y-dir)	0.852 Lpm (13.5 gph)	15 - Chopped UV/IR (halogen lamp) at 20 m
33	JP-8	Confined spill (y-dir)	0.17 Lpm (2.7 gph)	15 - Chopped UV/IR (halogen lamp) at 20 m
34	JP-8	Confined spill (y-dir)	0.17 Lpm (2.7 gph)	16 - Chopped IR (quartz heater) at 20 m
35	JP-8	Confined spill (y-dir)	0.17 Lpm (2.7 gph)	17 - Chopped IR (quartz heater) at 26 m
36	JP-8	Confined spill (y-dir)	0.852 Lpm (13.5 gph)	16 - Chopped IR (quartz heater) at 20 m
37	JP-8	Confined spill (y-dir)	0.852 Lpm (13.5 gph)	17 - Chopped IR (quartz heater) at 26 m
38	JP-8	Confined spill (y-dir)	1.703 Lpm (27.0 gph)	14
39	JP-8	Confined spill (y-dir)	1.703 Lpm (27.0 gph)	14
40	JP-5	Confined spill (y-dir)	1.703 Lpm (27.0 gph)	20
41	JP-5	Confined spill (y-dir)	0.852 Lpm (13.5 gph)	20
42	JP-5	Confined spill (y-dir)	0.852 Lpm (13.5 gph)	20
43	JP-5	Confined spill (y-dir)	0.17 Lpm (2.7 gph)	20
44	JP-5	Confined spill (y-dir)	0.17 Lpm (2.7 gph)	20
45	JP-5	Confined spill (y-dir)	1.703 Lpm (27.0 gph)	20
46	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	3 - Chopped IR (quartz heater) at 20 m
47	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	3 - Chopped IR (quartz heater) at 20 m
48	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	4 - Chopped IR (quartz heater) at 26 m
49	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	4 - Chopped IR (quartz heater) at 26 m
50	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	2 - Chopped UV/IR (halogen lamp) at 20 m
51	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	2 - Chopped UV/IR (halogen lamp) at 20 m
52	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	5 - Obstruction (0 to 1.34 m ht.)
53	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	5 - Obstruction (0 to 1.34 m ht.)
54	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	5 - Obstruction (0 to 1.34 m ht.)

Table 4. Summary of Optical Fire Detector Tests (Continued)

Test No.	Fuel	Fire	Fuel Flow/Amount	Test Scenario # and Conditions
55	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	6 - Obstruction (0 to 1.34 m ht.) moved away at 2 min
56	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	6 - Obstruction (0 to 1.34 m ht.) moved away at 2 min
57	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	7 - Obstruction (0.33 m to 2.25 m ht.)
58	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	7 - Obstruction (0.33 m to 2.25 m ht.)
59	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	7 - Obstruction (0.33 m to 2.25 m ht.)
60	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	8 -Obstruction (0.33 m to 2.25 m ht.) moved away at 2 min
61	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	8 -Obstruction (0.33 m to 2.25 m ht.) moved away at 2 min
62	JP-8	Unconfined spill	0.423 Lpm (6.7 gph)	7 - Obstruction (0.33 m to 2.25 m ht.)
63	JP-8	Unconfined spill	0.423 Lpm (6.7 gph)	7 - Obstruction (0.33 m to 2.25 m ht.)
64	JP-8	Unconfined spill	0.423 Lpm (6.7 gph)	8 -Obstruction (0.33 m to 2.25 m ht.) moved away at 2 min
65	JP-8	Unconfined spill	0.423 Lpm (6.7 gph)	8 -Obstruction (0.33 m to 2.25 m ht.) moved away at 2 min
66	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	2 - Chopped UV/IR (halogen lamp) at 20 m
67	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	2 - Chopped UV/IR (halogen lamp) at 20 m
68	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	3 - Chopped IR (quartz heater) at 20 m
69	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	3 - Chopped IR (quartz heater) at 20 m
70	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	4 - Chopped IR (quartz heater) at 26 m
71	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	4-Chopped IR (quartz heater) at 26 m - 30.5 m OFDs not on
72	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	4 - Chopped IR (quartz heater) at 26 m
73	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	1 - Leak in fuel line - HRR less than other similar tests
74	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	1
75	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	1
76	JP-8	Unconfined spill	0.423 Lpm (6.7 gph)	1
77	JP-8	Unconfined spill	0.423 Lpm (6.7 gph)	1
78	JP-8	Unconfined spill	0.852 Lpm (13.5 gph)	1
79	JP-8	Unconfined spill	0.852 Lpm (13.5 gph)	1
80	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	9 - Arc welding at 15 m (50 ft) from pad center
81	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	9 - Arc welding at 15 m (50 ft) from pad center

Table 4. Summary of Optical Fire Detector Tests (Continued)

Test No.	Fuel	Fire	Fuel Flow/Amount	Test Scenario # and Conditions
82	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	11 - Doors open, lights on
83	JP-8	Unconfined spill	0.17 Lpm (2.7 gph)	11 -Doors open, lights on
84	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	1
85	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	1
86	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	9 - Arc welding at 15 m (50 ft) from pad center
87	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	9 - Arc welding at 15 m (50 ft) from pad center
88	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	10 - Arc welding at 27 m (90 ft) from pad center
89	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	10 - Arc welding at 27 m (90 ft) from pad center
90	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	11 -Doors open, lights on
91	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	11 - Doors open, lights on
92	JP-5	Unconfined spill	1.703 Lpm (27.0 gph)	1
93	JP-5	Unconfined spill	1.703 Lpm (27.0 gph)	1
94	JP-5	Unconfined spill	1.703 Lpm (27.0 gph)	1
95	JP-5	Unconfined spill	1.703 Lpm (27.0 gph)	1
96	JP-5	Unconfined spill	0.17 Lpm (2.7 gph)	1
97	JP-5	Unconfined spill	0.17 Lpm (2.7 gph)	1
98	JP-5	Unconfined spill	0.17 Lpm (2.7 gph)	1
99	JP-8	Fixed quantity spill	2 L	12
100	JP-8	Fixed quantity spill	3 L	12
101	JP-8	Fixed quantity spill	3 L	12 - without wire frame in place
102	JP-8	Fixed quantity spill	3 L	12 - without wire frame in place
103	JP-8	Pan fire (0.61 x 0.61 m)	7 L	18 - 500 kW fire
104	JP-8	Pan fire (0.61 x 0.61 m)	7 L	18 - 500 kW fire
105	JP-8	Pan fire (0.91 m dia.)	10 L	18 - 1000 kW fire
106	JP-8	Pan fire (0.3 x 0.3 m)	1 L	18
107	JP-8	Pan fire (0.3 x 0.3 m) @ 15 m	0.5 L	18
108	JP-8	Pan fire (0.3 x 0.3 m) @ -15 m	0.5 L	18

Table 4. Summary of Optical Fire Detector Tests (Continued)

Test No.	Fuel	Fire	Fuel Flow/Amount	Test Scenario # and Conditions
109	Gasoline	Pan fire (0.3 x 0.3 m) @ -15 m	0.5 L	18
110	JP-8	Pan fire (0.91 m dia.)	10 L	18 - Rotate OFDs so fire goes from outside to inside FOV
111	JP-8	Pan fire (0.91 m dia.)	10 L	18 - Rotate OFDs so fire goes from outside to inside FOV
112	JP-8	Fixed quantity spill	3 L	12 - Align all detectors for direct line of sight with the fire
113	JP-8	Fixed quantity spill	3 L	12 - Align all detectors for direct line of sight with the fire
114	JP-8	Unconfined spill	1.703 Lpm (27.0 gph))	1 - Align all detectors for direct line of sight with the fire
115	JP-8	Unconfined spill	1.703 Lpm (27.0 gph)	1 - Align all detectors for direct line of sight with the fire
116	JP-8	Pan fire (0.61 x 0.61 m)	7 L	18 - Align all detectors for direct line of sight with the fire
117	JP-8	Pan fire (0.61 x 0.61 m)	7 L	18 - Align all detectors for direct line of sight with the fire
118	JP-8	Pan fire (0.91 m dia.)	10 L	18 - Align all detectors for direct line of sight with the fire
False001		--	--	Chopped UV/IR (halogen lamp) at 20 m
False002		--	--	Chopped IR (quartz heater) at 20 m
False003		--	--	Chopped IR (quartz heater) at 20 m & other disturbances
False004		--	--	
False005		--	--	Chopped IR (quartz heater) at 20 m
False006		--	--	Chopped IR (quartz heater) at 26 m
False007		--	--	Blown halogen lamp, pellet gun shot
False008		--	--	Blown halogen lamp without cover and 3 drops of oil
False009		--	--	Blown halogen lamp, with glass relief tip broken off
False010		--	--	Arc welding at 15 m (50 ft) from pad center
False011		--	--	Chopped IR at 26 m & Incandescent bulb, pellet gun shot
False012		--	--	Chopped IR at 26 m & Incandescent bulb, pellet gun shot
False013	--	--	--	Arc welding at 27 m (90 ft) from pad center

Table 5. Summary of Tests Arranged by Scenario *

Scenario		Fuel Flow Rate (Lpm)**				Volume of Fuel (L)			Pan size		
No.	Description	0.17	0.42	0.85	1.7	1	2	3	0.3 x 0.3 m	0.6 x 0.6 m	0.91 m dia.
JP-8											
1	Unconfined	1,2,73, 74,75	3,4, 76,77	5,6,78, 79	7,8,84,85, 114,115						
2	with chopped UV/IR	66,67			50,51						
3	with chopped IR at 20 m	68,69			46,47						
4	with chopped IR at 26 m	70,71, 72			48,49						
5	with obstruction 0-1.34 m ht				52,53,54						
6	with moving obstruction 0-1.34 m ht				55,56						
7	with obstruction 0.3-2.3 m ht		62,63		57,58,59						
8	with moving obstruction 0.3-2.3 m ht		64,65		60,61						
9	with arc welding at 15 m	80,81			86,87						
10	with arc welding at 27 m				88,89						
11	with doors open and lights on	82,83			90,91						
12	**Fixed Quantity**					9	10,11,99	12,100,101 102,112, 113			
13	**Confined** (x-dir)	17,18	19,20, 24,25	21,22, 23							
14	**Confined** (y-dir)	26,30	27	28,29	38,39						
15	with chopped UV/IR	33		31,32							
16	with chopped IR @20 m	34		36							
17	with chopped IR @26 m	35		37							

Table 5. Summary of Tests Arranged by Scenario * (Continued)

Scenario		Fuel Flow Rate (Lpm)**				Volume of Fuel (L)			Pan size		
No.	Description	0.17	0.42	0.85	1.7	1	2	3	0.3 x 0.3 m	0.6 x 0.6 m	0.91 m dia.
18	**Pan**								106,107 (at 50 ft),108 (at -50 ft)	13,103,104, 116,117	15,105, 118
											110,111 (OFDs rotated)
JP-5											
19	**Unconfined**	96,97, 98			92,93,94, 95						
20	Confined (y-dir)	43,44		41,42	40,45						
Gasoline											
21	Pan								109 (at -15.2 m (50 ft))	14	16

* Numbers correspond to the test numbers of each test conducted for the specified scenario.
** Flow rates are nominal flow meter test conditions and have not been corrected for actual fuel flow rates.

a summary of all of the fire tests arranged by scenario. The majority of tests were conducted using JP-8 fuel. Also, not all scenarios were conducted for each fuel type. Gasoline was used only with pan fires. In most cases, a minimum of 2 tests were conducted for each scenario. Since the unconfined JP-8 fires (Scenario No. 1) were used as the basis for the bulk of the tests, multiple tests were conducted at each fuel flow rate to establish the repeatability of the test method. The heat release rate measurements serve as a basis for comparing test-to-test repeatability.

6.1 OFD Response

The alarm times for each OFD are presented in the tables of Appendix C. The appendix is divided into 21 sections corresponding to each of the test scenarios as listed in Table 5. Each section contains two types of tables, one presenting OFD alarm times and the second presenting the heat release rate (HRR) at the time of alarm for each OFD. Table 6 shows an example of the first type of table which presents the time of alarm for each of the 36 OFDs for all of the tests of a given scenario. Table 6 presents the OFD results for all of the 1.7 Lpm unconfined spill fire tests (i.e., Scenario 1). Tests 7, 8, 84, and 85 represent replicate tests. Tests 114 and 115 were the same fire scenario, but they were different in that all of the OFDs were aligned with the fire to be in direct line of sight (this is discussed below). Besides the alarm times, Table 6 presents the number of alarms per tests conducted, the average alarm time, the standard deviation of the time and the variance for each OFD. The standard deviation and percent variance can be used as measures of the repeatability of alarm results from test to test.

Table 7 shows an example of the second type of table presented in Appendix C for each test scenario. Table 7 is similar to Table 6 except that it includes the heat release rate measurement at the time of alarm for each OFD instead of the time to alarm. These results are helpful in correlating OFD response to fire size. Using fire size allows detector performance to be compared on a common basis between tests with different fire scenarios. However, due to alarms occurring during times of rapid changes in heat release rate (i.e., during fire growth), there is much more uncertainty in stating the HRR at the alarm time then there is in the alarm time.

6.1.1 Rank Ordering of OFDs

Each test scenario was evaluated using the tables in Appendix C. The evaluation consisted of identifying the detectors which alarmed for each test of the scenario and summarizing the response times of each detector model at the various positions. Consider Table 6 for example: for the four similar tests (7, 8, 84, and 85), it was noted that OFD1 (UV/IR) and 6 (3-IR) alarmed for all locations. OFD4 (2-IR) alarmed for all tests and locations except one test (84) at the vertical-off-axis position at 46 m (OFD 4E). OFD3 (3-IR) alarmed for all tests and locations except for two tests (8 and 84) at the horizontal-and-vertical-off-axis position at the 46 m location (OFD 3F). OFD2 and 5 (both UV/IR) only alarmed for the 31 m direct-line-of-sight positions (OFD 2A and OFD 5A). Along with this summary of the alarm responses, the range and average response times for each detector model and position was recorded. For

Table 6. Example of Table in Appendix C, Which Presents the Alarm Times (seconds) for Each OFD and All Tests of the Same Scenario

Fuel Flow Rate: 1.7 Lpm Scenario: Unconfined Fuel: JP-8										
OFD Unit/ Location	Test						Alarms/ Tests	Average	Standard Deviation	Variance (%)
	7	8	84	85	114	115				
OFD1A	29	32	28	22	24	25	4/4	28	4.2	15.1
OFD2A	51	49		70			4/4	57	11.6	20.5
OFD3A	26	28	28	20	24	22	4/4	26	3.8	14.8
OFD4A	51	58	48	29	35	32	4/4	47	12.4	26.7
OFD5A	42	44	74	36	54	58	4/4	49	17.0	34.7
OFD6A	23	27	27	24	24	26	4/4	25	2.1	8.2
OFD1B	31	34	32	21	25	22	4/4	30	5.8	19.7
OFD2B							0/4			
OFD3B	28	32	37	22	24	22	4/4	30	6.3	21.3
OFD4B	55	73	52	30	35	34	4/4	53	17.6	33.6
OFD5B					54	60	0/4			
OFD6B	23	27	27	22	27	26	4/4	25	2.6	10.60
OFD1C	29	32	36	22	26	24	4/4	30	5.9	19.9
OFD2C							0/4			
OFD3C	28	31	37	22	24	22	4/4	30	6.2	21.2
OFD4C	49	56	51	31	36	34	4/4	47	10.9	23.3
OFD5C					54	57	0/4			
OFD6C	23	30	27	22	21	26	4/4	26	3.7	14.5
OFD1D	35	35	35	29	39	29	4/4	34	3.0	9.0
OFD2D							0/4			
OFD3D	28	30	37	22	27	26	4/4	29	6.2	21.1
OFD4D	55	80	69	34	57	62	4/4	60	19.8	33.3
OFD5D							0/4			
OFD6D	28	35	30	25	29	26	4/4	30	4.2	14.2
OFD1E	47	52	55	61	62	46	4/4	54	5.9	10.9
OFD2E							0/4			
OFD3E	40	43	54	32	29	32	4/4	42	9.1	21.6
OFD4E	56	56		57	47	56	3/4	56	0.6	1.0
OFD5E							0/4			
OFD6E	31	35	33	22	29	29	4/4	30	5.7	19.0
OFD1F	44	51	52	48	45	42	4/4	49	3.6	7.4
OFD2F							0/4			
OFD3F	38			92	29	32	3/4	65	38.2	58.7
OFD4F	57	56	69	37	47	60	4/4	55	13.2	24.2
OFD5F							0/4			
OFD6F	28	32	38	29	29	26	4/4	32	4.5	14.2

Table 7. Example of Tables in Appendix D, Which Presents the Heat Release Rate (MW) at the Time of Alarm for Each OFD and All Tests of the Same Scenario

Heat Release Rates at Time of Detection (MW)							
OFD Unit/ Location	Test				Average	Standard Deviation	Variance (%)
	7	8	84	85			
OFD1A	0.17	0.17	0.07	0.15	0.14	0.05	34
OFD2A	0.67	0.67		0.91	0.75	0.14	18
OFD3A	0.12	0.1	0.07	0.11	0.10	0.02	22
OFD4A	0.67	0.83	0.37	0.3	0.54	0.25	46
OFD5A	0.52	0.52	0.86	0.42	0.58	0.19	33
OFD6A	0.08	0.1	0.05	0.2	0.11	0.07	60
OFD1B	0.21	0.22	0.11	0.13	0.17	0.06	33
OFD2B							
OFD3B	0.15	0.15	0.18	0.15	0.16	0.01	10
OFD4B	0.65	0.8	0.44	0.24	0.53	0.24	46
OFD5B							
OFD6B	0.08	0.14	0.05	0.15	0.11	0.05	46
OFD1C	0.17	0.17	0.1	0.15	0.15	0.03	22
OFD2C							
OFD3C	0.15	0.15	0.18	0.15	0.16	0.01	10
OFD4C	0.65	0.8	0.44	0.24	0.53	0.24	46
OFD5C							
OFD6C	0.08	0.14	0.05	0.15	0.11	0.05	46
OFD1D	0.32	0.25	0.15	0.3	0.26	0.08	30
OFD2D							
OFD3D	0.15	0.14	0.18	0.15	0.16	0.02	11
OFD4D	0.72	0.89	0.81	0.39	0.70	0.22	31
OFD5D							
OFD6D	0.15	0.25	0.09	0.2	0.17	0.07	40
OFD1E	0.62	0.74	0.53	0.85	0.69	0.14	20
OFD2E							
OFD3E	0.47	0.5	0.51	0.35	0.46	0.07	16
OFD4E	0.72	0.8		0.8	0.77	0.05	6
OFD5E							
OFD6E	0.21	0.25	0.12	0.15	0.18	0.06	32
OFD1F	0.56	0.72	0.46	0.66	0.60	0.11	19
OFD2F							
OFD3F	0.41			0.31	0.36	0.07	20
OFD4F	0.73	0.8	0.81	0.44	0.70	0.17	25
OFD5F							
OFD6F	0.15	0.17	0.2	0.3	0.21	0.07	32

example, OFD6 (3-IR) had average alarm times of 25 seconds for all of the detectors at 31 m (OFD 6A, B and C) and about 31 seconds for all of the detectors at 46 m (OFD 6 D, E and F).

Using the response data for each test scenario allows a relative rank ordering of the detectors. Continuing with the example above, the rank order of the OFDs would be:

(6,1), 4, 3, (5,2),

where the numbers stand for each of the OFD model types. The parenthesis indicate that the detectors rank evenly. Note that in this example OFD3 ranked third, but actually performed quite well, even compared to models OFD6 and OFD1, by detecting all fires except two tests at the most remote location and orientation. Therefore, this ranking provides a means to identify overall relative performance but must be considered with other criteria to assess individual detector performance. Table 8 provides a summary of the rank order analysis of all detectors for every test scenario. The format mirrors that of Table 5 showing the tests scenarios. The results presented in Table 8 clearly identify OFD6 (3-IR) as the best performer with respect to ability to detect fires over the range of scenarios studied. Also, detectors OFD5 and 2 (both UV/IR) were the worst performers relative to the other OFDs evaluated.

Examining the unconfined fire scenarios 1-11 shown in Table 8 reveals that OFD1 (UV/IR) and OFD4 (2-IR) performed slightly better than OFD3 (3-IR) with larger fires (i.e., 1.7 Lpm flow rates). However, with the smaller fires, OFD3 performed better than OFD1 and 4. Keep in mind that these results represent only a relative ranking. Section 6.3 discusses the results of detector performance with respect to fire size in more quantitative terms.

The rank order achieved for the fixed quantity spill fire scenarios agrees well with the unconfined spill fire scenario results (Scenario 12 compared to scenarios 1-11). OFD6 (3-IR) consistently performed the best and OFD2 and 5 (both UV/IR) consistently were the worst performers. The other three detectors, OFD1 (UV/IR), OFD3 (3-R) and OFD4 (2-IR) had mixed rankings.

The rank order results indicate that the JP-8 pan fire tests did not provide as much differentiation between OFD models as did the spill fire scenarios (unconfined and fixed quantity). Otherwise, the relative rank order was similar for the different test scenarios. The JP-8 pan fire rankings (Scenario 18) compare fairly close with the gasoline pan fire rankings (Scenario 21) with primary difference at the 0.9 m diameter fire. However, the difference is rather small. In Scenario 18, OFD6 and 4 alarmed at all locations. In Scenario 21 with the gasoline pan fires, OFD4, 3 and 1 alarmed at all locations and OFD6 alarmed at all except at the 41 m horizontal and vertical off-axis position.

6.1.2 <u>OFD Response Times</u>

Tables 9a-9f present response times for each OFD model at selected locations and test scenarios. The tables are separated by OFD models. The values presented are the range of alarm

Table 8. Descending Order of OFD Performance Based on Ability of Detector to Alarm

Scenario		Fuel Flow Rate (Lpm)				Volume of Fuel (L)			Pan Size		
No.	Description	0.17	0.42	0.85	1.7	1	2	3	0.3 x 0.3 m	0.6 x 0.6 m	0.91 m dia.
JP-8											
1	**Unconfined**	6,3,1, (5,4,2)	6,3,1,4, 5,2	(6,3,1), 4,5,2	(6,1),4, 3, (5,2)						
2	with chopped UV/IR	6,3,(5, 4,2,1)			(6,4),(3, 1),5,2						
3	with chopped IR at 20 m	6,(3,1), (5,4,2)			(6,1),3, 4,5,2						
4	with chopped IR at 26 m	6,1,3,5, (4,2)			6,1,3,(4, 5),2						
5	with obstruction 0-1.34 m ht				6,4,3,5, (1,2)						
6	with moving obstruction 0-1.34 m ht				(6,4),1, 3,5,2						
7	with obstruction 0.3-2.3 m ht		6,(3,1,4, 5,2)		6,4,1,3, (5,2)						
8	with moving obstruction 0.3-2.3 m ht		6,3,1,4, (5,2)		(6,4,1), 3,5,2						
9	with arc welding at 15 m	6,3,(5, 4,2,1)			(6,4,1), 3,5,2						
10	with arc welding at 27 m				(6,4,1), 3,5,2						
11	with doors open and lights on	6,3,1,4, (5,2)			(6,4,1), 3,(5,2)						
	Overall Rank:	6,3,1,4, 5,2	6,3,1,4, 5,2	(6,3,1), 4,5,2	6,(1,4), 3,5,2						
12	**Fixed Quantity**					6,3,1,4, (5,2)	6,3,1,4, (5,2)	(6,4),(3, 1),5,2			
13	**Confined** (x-dir)	6,3,1, (5,4,2)	6,3,1,4, (5,2)	6,3,1,4, (5,2)							
14	**Confined** (y-dir)	6,3,(5, 4,2,1)	6,3,(1, 4),(5,2)	6,3,1,4, (5,2)	6,3,1,4, (5,2)						

Table 8. Descending Order of OFD Performance Based on Ability of Detector to Alarm

Scenario		Fuel Flow Rate (Lpm)				Volume of Fuel (L)			Pan Size		
No.	Description	0.17	0.42	0.85	1.7	1	2	3	0.3 x 0.3 m	0.6 x 0.6 m	0.91 m dia.
15	with chopped UV/IR	6,3,(5, 4,2,1)		6,3,(1,4, 5,2)							
16	with chopped IR @20 m	6,3,(5, 4,2,1)		6,3,1,(4, 5,2)							
17	with chopped IR @26 m	6,(3,2), (5,4,1)		6,1,(3,5, 2),4							
18	**Pan**								6,3,(5,4,2,1)	(6,3,4),1,5,2	(6,4)3,1,5,2
JP-5											
19	**Unconfined**	6,3,1, (5,4,2)			1,(6,3,4), 5,2						
20	**Confined** (y-dir)	6,3,(5, 4,2,1)		6,3,(1, 4),(5,2)	6,3,1,4, (5,2)						
Gasoline											
21	**Pan**								6,3,(5,4,2,1)	(6,3,4,1),5,2	(4,3,1),6,5,2

Table 9a. Range of Alarm Times for Selected Detector Locations and Fire Scenarios for OFD1 (UV/IR)

Fire Size	OFD Distance from Fire and Orientation			
	31 m, DLS	31 m, HVOA	46 m, DLS	46 m, HVOA
Unconfined Spill Fires				
~ 0.08 - 0.11 MW (0.17 Lpm)	47-111 s	NA, 60-113 s	NA	NA
~ 0.25 MW (0.42 Lpm)	26-34 s	28-38 s	NA, 32-38 s	NA, 73-90 s
~ 0.45-0.55 MW (0.85 Lpm)	19-26 s	22-28 s	22-35 s	42-58 s
~ 0.85-0.95 MW (1.7 Lpm)	22-32 s	22-36 s	29-35 s	44-52 s
Unconfined with 0.3-2.3 m Obstruction				
~ 0.85-0.95 MW (1.7 Lpm)	28-39 s	42-45 s	40-54 s	NA
Pan Fires				
~ 0.1 MW (0.3 x 0.3 m)	NA	NA	NA	NA
~ 0.35-0.4 MW (0.6 x 0.6 m)	32-40 s	28-47 s	41-66 s	NA, 139 s
~ 0.6-0.75 MW (0.9 m dia)	19, 38 s	32, 43 s	38, 55 s	NA, 69 s

Table 9b. Range of Alarm Times for Selected Detector Locations and Fire Scenarios for OFD2 (UV/IR)

Fire Size	OFD Distance from Fire and Orientation			
	31 m, DLS	31 m, HVOA	46 m, DLS	46 m, HVOA
Unconfined Spill Fires				
~ 0.08 - 0.11 MW (0.17 Lpm)	NA	NA	NA	NA
~ 0.25 MW (0.42 Lpm)	NA	NA	NA	NA
~ 0.45-0.55 MW (0.85 Lpm)	NA	NA	NA	NA
~ 0.85-0.95 MW (1.7 Lpm)	NA, 49-70 s	NA	NA	NA
Unconfined with 0.3-2.3 m Obstruction				
~ 0.85-0.95 MW (1.7 Lpm)	NA	NA	NA	NA
Pan Fires				
~ 0.1 MW (0.3 x 0.3 m)	NA	NA	NA	NA
~ 0.35-0.4 MW (0.6 x 0.6 m)	NA	NA	NA	NA
.~ 0.6-0.75 MW (0.9 m dia)	47, 135 s	NA	NA	NA

Table 9c. Range of Alarm Times for Selected Detector Locations and Fire Scenarios for OFD3 (3-IR)

Fire Size	OFD Distance from Fire and Orientation			
	31 m, DLS	31 m, HVOA	46 m, DLS	46 m, HVOA
Unconfined Spill Fires				
~ 0.08 - 0.11 MW (0.17 Lpm)	29-77 s	63-103 s	49-99 s	NA
~ 0.25 MW (0.42 Lpm)	21-28 s	29-39 s	28-37 s	NA, 73 s
~ 0.45-0.55 MW (0.85 Lpm)	19-23 s	21-27 s	22-26 s	35-47 s
~ 0.85-0.95 MW (1.7 Lpm)	20-28 s	22-37 s	22-37 s	NA, 38, 92 s
Unconfined with 0.3-2.3 m Obstruction				
~ 0.85-0.95 MW (1.7 Lpm)	33-38 s	NA	35-43 s	NA
Pan Fires				
~ 0.1 MW (0.3 x 0.3 m)	51 s	66 s	64 s	NA
~ 0.35-0.4 MW (0.6 x 0.6 m)	16-20 s	18-21 s	18-22 s	34-41 s
.~ 0.6-0.75 MW (0.9 m dia)	15, 17 s	17, 20 s	16, 19 s	NA, 25 s

Table 9d. Range of Alarm Times for Selected Detector Locations and Fire Scenarios for OFD4 (2-IR)

Fire Size	OFD Distance from Fire and Orientation			
	31 m, DLS	31 m, HVOA	46 m, DLS	46 m, HVOA
Unconfined Spill Fires				
~ 0.08 - 0.11 MW (0.17 Lpm)	NA	NA	NA	NA
~ 0.25 MW (0.42 Lpm)	38-70 s	NA, 69-81 s	NA, 84 s	NA
~ 0.45-0.55 MW (0.85 Lpm)	32-37 s	33-45 s	38-57 s	NA, 52-89 s
~ 0.85-0.95 MW (1.7 Lpm)	29-58 s	31-56 s	34-80 s	37-69 s
Unconfined with 0.3-2.3 m Obstruction				
~ 0.85-0.95 MW (1.7 Lpm)	43-52 s	43-64 s	53-64 s	NA, 56
Pan Fires				
~ 0.1 MW (0.3 x 0.3 m)	NA	NA	NA	NA
~ 0.35-0.4 MW (0.6 x 0.6 m)	31-38 s	43-47 s	41-46 s	64-74 s
.~ 0.6-0.75 MW (0.9 m dia)	22, 24 s	33, 35 s	32, 38 s	41, 43 s

Table 9e. Range of Alarm Times for Selected Detector Locations and Fire Scenarios for OFD5 (UV/IR)

Fire Size	OFD Distance from Fire and Orientation			
	31 m, DLS	31 m, HVOA	46 m, DLS	46 m, HVOA
Unconfined Spill Fires				
~ 0.08 - 0.11 MW (0.17 Lpm)	NA	NA	NA	NA
~ 0.25 MW (0.42 Lpm)	NA	NA	NA	NA
~ 0.45-0.55 MW (0.85 Lpm)	42-84 s	NA	NA	NA
~ 0.85-0.95 MW (1.7 Lpm)	36-74 s	NA	NA	NA
Unconfined with 0.3-2.3 m Obstruction				
~ 0.85-0.95 MW (1.7 Lpm)	NA	NA	NA	NA
Pan Fires				
~ 0.1 MW (0.3 x 0.3 m)	NA	NA	NA	NA
~ 0.35-0.4 MW (0.6 x 0.6 m)	43-63 s	NA	NA	NA
.~ 0.6-0.75 MW (0.9 m dia)	35, 45 s	NA	NA, 81 s	NA

Table 9f. Range of Alarm Times for Selected Detector Locations and Fire Scenarios for OFD6 (3-IR)

Fire Size	OFD Distance from Fire and Orientation			
	31 m, DLS	31 m, HVOA	46 m, DLS	46 m, HVOA
Unconfined Spill Fires				
~ 0.08 - 0.11 MW (0.17 Lpm)	23-42 s	23-42 s	33-80 s	35-86 s
~ 0.25 MW (0.42 Lpm)	20-30 s	24-29 s	28-30 s	25-33 s
~ 0.45-0.55 MW (0.85 Lpm)	19-22 s	19-21 s	22-27 s	21-27 s
~ 0.85-0.95 MW (1.7 Lpm)	23-27 s	22-30 s	25-35 s	28-38 s
Unconfined with 0.3-2.3 m Obstruction				
~ 0.85-0.95 MW (1.7 Lpm)	33-44 s	34-44 s	39-49 s	42-49 s
Pan Fires				
~ 0.1 MW (0.3 x 0.3 m)	37	34	53	68
~ 0.35-0.4 MW (0.6 x 0.6 m)	19-22 s	16-22 s	20-25 s	23-26 s
.~ 0.6-0.75 MW (0.9 m dia)	17, 21 s	16, 21 s	19, 21 s	24, 25 s

times that occurred for repeat tests of the given detector location and fire scenario. If only one test was conducted, then a single value is presented. If two tests were conducted, then two values separated by a comma are presented. Otherwise, the range of times represents three or more tests. An entry of "NA" indicates that no alarm occurred. In some instances, "NA" will appear with times; this indicates that the detector alarmed in some tests and not in others of the same scenario.

Three test conditions are presented to provide a general overview of detector performance. Unconfined spill fires resulting in four different steady-state heat release rates provide a means to assess OFD performance with respect to fire size and detector location and orientation. Orientation designations of DLS and HVOA stand for direct line of sight and horizontal and vertical off-axis. The pan fire data is provided as a baseline for comparison of these test results to existing data published by manufacturers and from previous studies. The 0.3-2.3 m high obstructed fire test is provided as it presents one of the greatest challenges to OFD detection capability in terms of obstruction.

Based on Tables 9a-9f, the following observations can be drawn for detectors with unobstructed views of unconfined spill fires:

OFD1 (UV/IR):
- 100 kW fire detectable at 31 m DLS, and for a few tests at 31 m off-axis (47 to 113 s alarm times).
- 1000 kW fires detectable at all locations (22 to 52 s alarm times).

OFD2 and OFD5 (UV/IR):
- Unable to detect 100 kW fires at 31 and 46 m DLS.
- Only able to detect 500 to 1000 kW fires at 31 m DLS (42 to 84 s alarm times).
- Unable to detect any fire conducted at off-axis positions.

OFD4 (2-IR):
- Unable to detect 100 kW fires at 31 and 46 m.
- Able to detect 500 kW fires at all locations in 32 to 89 s, except that at 46 m HVOA, some tests were not detected.
- 1000 kW fires detectable at all locations within 29 to 80 s.

OFD3 and OFD6 (3-IR):
- 100 kW fires detectable at all locations in 23 to 103 s, except OFD3 HVOA.
- 1000 kW fires detectable at all locations in 20 to 38 s, except OFD3 which did not detect 2 of 4 fires at 46 m HVOA; the other two fires were detected in 38 and 92 s.

When the fire was obstructed, fewer alarms occurred and longer alarm times were observed for some of the detectors that did respond. OFD1 (UV/IR), OFD3 (3-IR), and OFD4 (2-IR) were unable to detect the 1000 kW fire at 46 m, HVOA. OFD3 also was unable to detect the fires at the 31 m HVOA location. Alarm times were generally 10 seconds slower.

6.2 Uniformity in Performance of OFD Units

At the end of the test program, all 36 OFDs were aligned for direct line of sight with the fire. Once realigned, seven tests were conducted with different fire scenarios to assure that all six of the OFD units of a given model were performing uniformly. Tests 112 through 118 consisted of 1.7 Lpm unconfined spill fires, 3 L fixed quantity spill fires, 0.91 m diameter and 0.6 x 0.6 m pan fires. For each test, the response of each detector (did it alarm or not) and the alarm times were compared between each unit of a given model at both the 31 and 46 m OFD locations. The units of each model at a location responded uniformly for all of the tests. That is, the similar detectors either all alarmed or none alarmed. Additionally, the alarm times agreed well, varying from 0 to 5 seconds for almost all detectors and all tests. Many units alarmed within 2 seconds of each other. Overall, the results of these tests demonstrated that performance comparisons of the optical fire detectors at different orientations and locations are valid.

6.3 Fire Test Repeatability (Heat Release Rate)

Appendix D contains heat release rate (HRR) plots for each test scenario. The plots are grouped according to the columns in Table 5, such that all test scenarios for the same fuel and fire type are together. This arrangement allows easy comparison of tests with similar fire scenarios to assess repeatability. In plots in Sections 6.3.1 to 6.3.5 where ignition occurred at different times, data has been adjusted so that time of ignition for all tests plotted is at 60 seconds.

6.3.1 Unconfined Spill Fires

Figure 14 shows a photograph of a typical unconfined spill fire. Comparison of the HRR curves for all of the 1.7 Lpm JP-8 fires (Scenarios 1 to 11 in Table 5) reveals that the scenario was quite reproducible. Figure 15 shows the HRR curves as a function of time for the Scenario 1, 1.7 Lpm fires. There is some variation in the time at which the fire spread; however, the rate of rise of the HRR is nearly constant for all tests. The repeatability of the fire scenario is better demonstrated in Figure 16 which shows the HRR curves for all 1.7 Lpm JP-8 test fires (Scenarios 1 to 11). In Figure 16, the growth rate lies within a narrow band for all but one or two of the 56 tests plotted. The maximum HRR, typically ranges from about 800 to 900 kW, but reaches values upward of 1100 kW.

The effect of temperature on the 1.7 Lpm unconfined fuel spill fire scenarios was minimal. Table 10 presents the average temperatures of the fuel, the surface of the concrete pad and inside the concrete (within 6 mm of the surface) for the 1.7 Lpm JP-8 spill fire tests. The tests are grouped according to test scenarios as shown in Table 5. The measured temperatures show that the initial fuel temperature (i.e., in the tank) was essentially the same for all tests, within 5°C. For sequential tests, there was typically a 1 to 2°C temperature rise in the fuel. This was due to the small radiative heating of the fuel tank from the test fires.

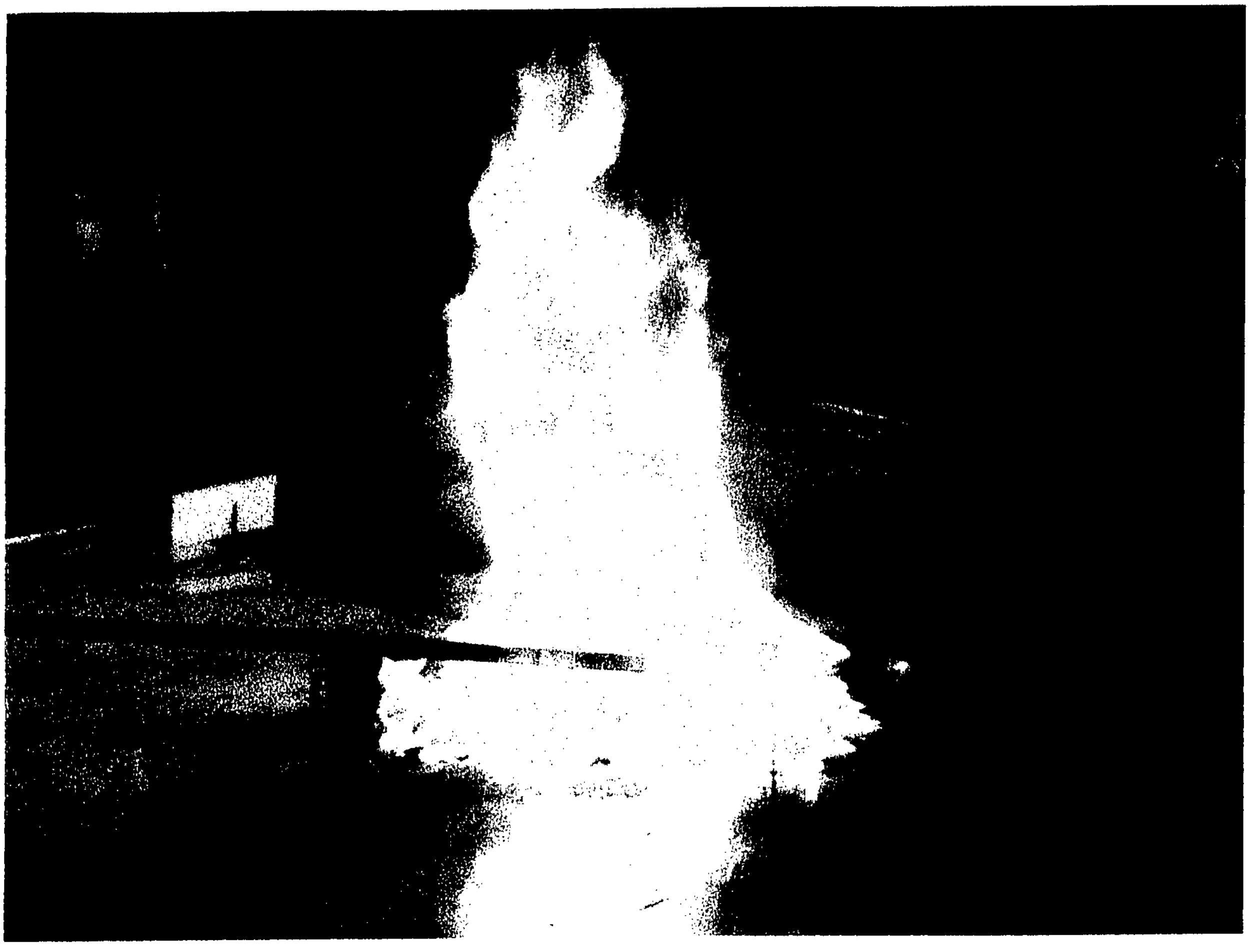


Fig. 14 – Photograph of a typical unconfined spill fire test (Test 77)

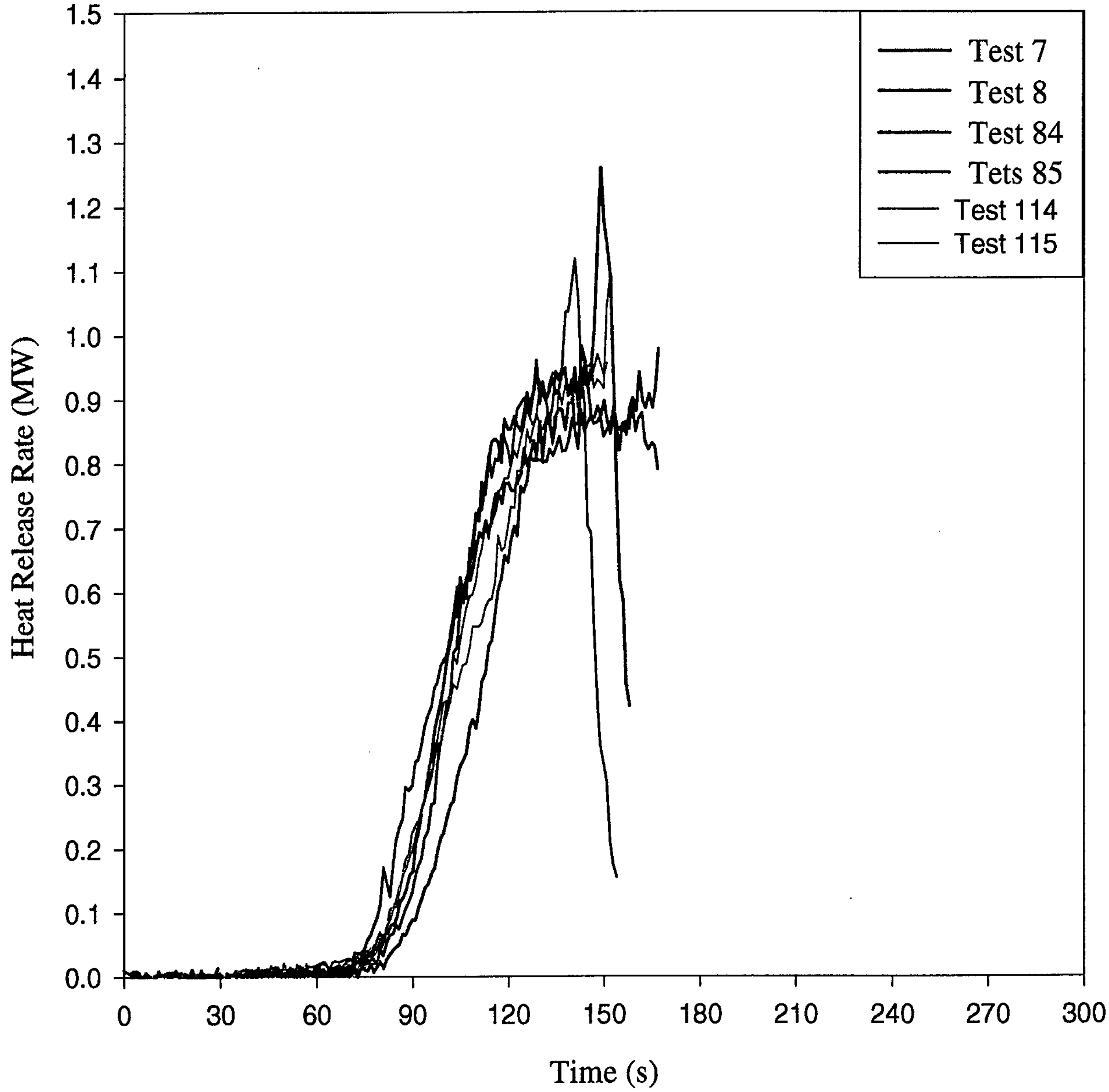


Fig. 15 – Comparison of heat release rates for Scenario 1, 1.7 Lpm unconfined JP-8 spill fires

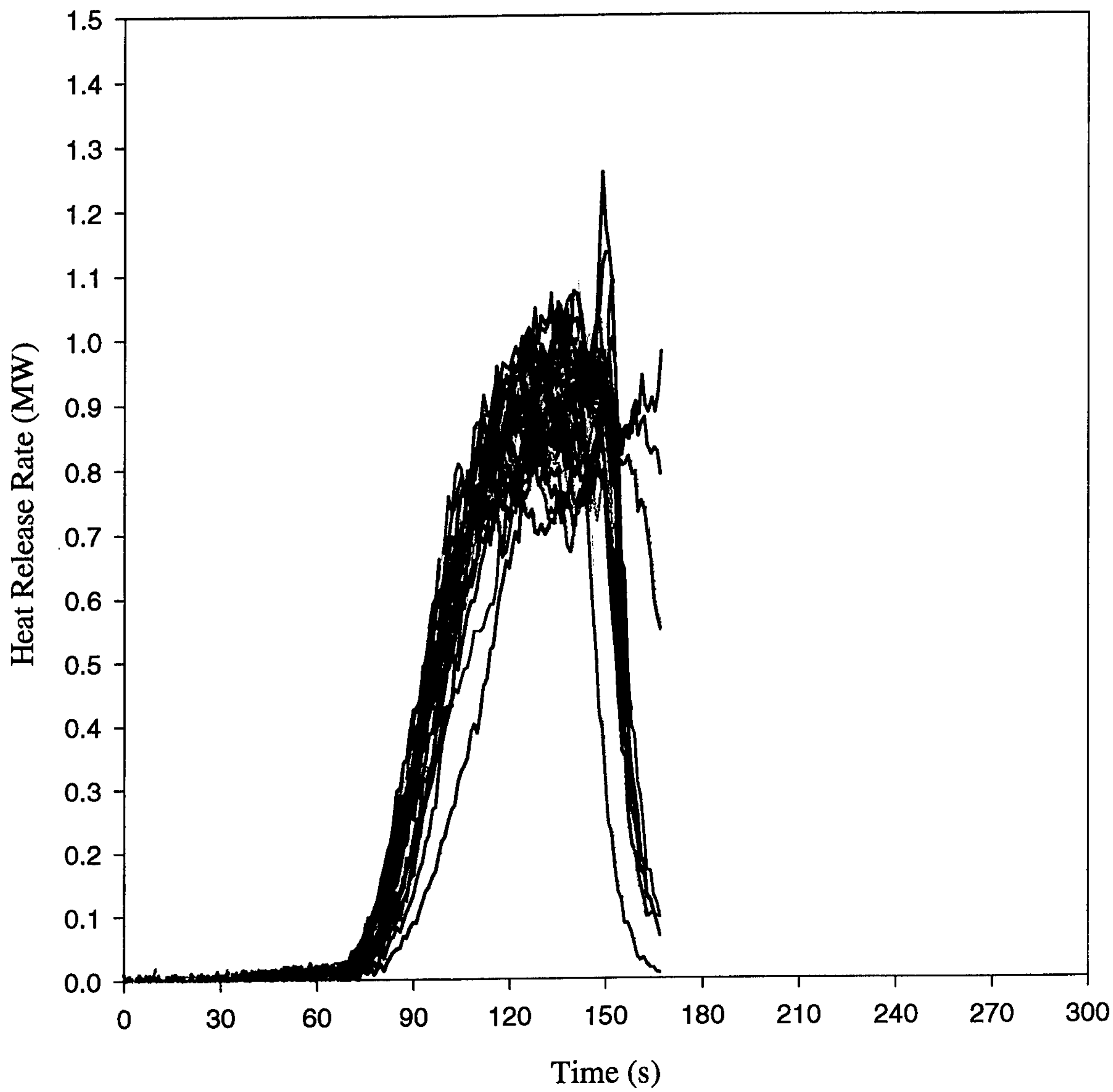


Fig. 16 – Comparison of heat release rates for all 1.7 Lpm JP-8 unconfined spill fires (Scenarios 1-11)

Table 10. Temperature Measurements for 1.7 Lpm Unconfined JP-8 Spill Fire Tests

Scenario	Test	Initial Fuel Temp (°C)	In-slab Temp (°C)	Surface Temp (°C)
1	7	27	41	34
	8	27	43	35
	84	29	49	36
	85	30	49	40
	114	27	28	34
	115	28	37	39
2	50	24	51	41
	51	25	54	43
3	46	23	38	28
	47	24	43	31
4	48	25	44	37
	49	25	47	38
5	52	26	53	36
	53	26	54	38
	54	28	55	43
6	55	28	58	43
	56	28	59	45
7	57	28	59	41
	58	28	60	46
	59	29	61	49
8	60	29	64	46
	61	29	64	46
9	86	30	51	44
	87	31	53	47
10	88	30	56	44
	89	31	57	47
11	90	32	59	48
	91	32	60	52

There was a noticeable difference in the concrete slab temperatures between some of the 1.7 Lpm JP-8 spill fire tests, up to 27°C in the slab and 24°C on the surface. Comparing the temperature data with the HRR data (see Appendix D and Figures 15 and 16) reveals that the continuously flowing, unconfined fires were effected very little by the temperature of the concrete. As temperature increased, a slight increase in peak HRR was observed for the 1.7 Lpm spills, approximately 10 to 15 per cent (100 kW). This observation holds in a general sense, however, not all specific cases reveal this trend. The growth rate of the fire, as measured by the slope of the HRR curve versus time, was not significantly effected by the change in the concrete slab temperatures.

The effect of temperature was more pronounced with the smaller flow rate fires (i.e., 0.17 and to some extent 0.42 Lpm). With the 0.17 Lpm fires, the differences in concrete temperature between tests was greater than in the 1.7 Lpm tests. In Table 11, the maximum differences were 36°C for in-slab temperatures and 21°C for surface temperatures. The effect was a noticeable increase in the fire growth rate with increase in temperature. For tests of similar temperature conditions, HRR curves agreed very well (see Figures in Appendix D). Figure 17 shows the general difference in HRR profiles as a function of concrete temperature. Though the slopes (fire growth rates) are different, there is good agreement in HRR data overall. It is concluded that the size of the continuously flowing unconfined spill fires are primarily dependent on the fuel flow rate, and the concrete temperature has a minor second order effect, which decreases with increasing fuel flow rate.

There was no systematic evaluation nor test data to determine the effect of initial fuel temperature on the continuously flowing unconfined spill fire scenarios. Overall, the tests conducted demonstrate that a repeatable spill fire scenario can be provided with the continuously flowing unconfined fuel supply system.

6.3.2 Confined Spill Fire Scenarios

The heat release data for the confined spill fire scenarios are generally in good agreement; however, some differences do exist which appear to be attributable to temperature. Figure 18 shows a photograph of a typical confined spill fire test. Figures 19, 20, and 21 present comparisons of HRR plots for similar JP-8 confined spill test scenarios. Figure 19 shows the comparison of HRR plots for all of the 0.17 Lpm JP-8 spill fires confined in the Y direction. Table 12 summarizes the initial fuel and concrete slab temperatures for the three confined spill fire scenarios reported in Figures 19 to 21. Only in-slab temperatures are reported; during the confined spill fires the surface thermocouples were not in contact with the concrete (the wire frame with the thermocouples was elevated above the angle iron which made the confined areas).

Comparing the temperature data in Table 12 with respect to the corresponding HRR plots, it is observed that higher concrete temperatures resulted in more rapid development of the fire. This is observed in Figure 19, between Tests 30, 33, and 34 (temperatures of 63 to 71°C) and Tests 26 and 35 (temperatures of 42 and 40°C), which had slower growth rates and lower steady-

Table 11. Temperature Measurements for 0.17 Lpm Unconfined JP-8 Spill Fire Tests

Scenario	Test	Temperature (C)		
		Fuel	In-slab	Surface
1	1	24	34	29
	2	25	34	29
	73	25	43	31
	74	26	43	33
	75	27	43	35
2	66	28	69	49
	67	28	69	50
3	68	28	70	49
	69	28	70	47
4	70	28	70	48
	71	28	70	48
	72	27	70	46
9	80	28	50	40
	81	28	50	41
11	82	28	52	42
	83	28	53	41

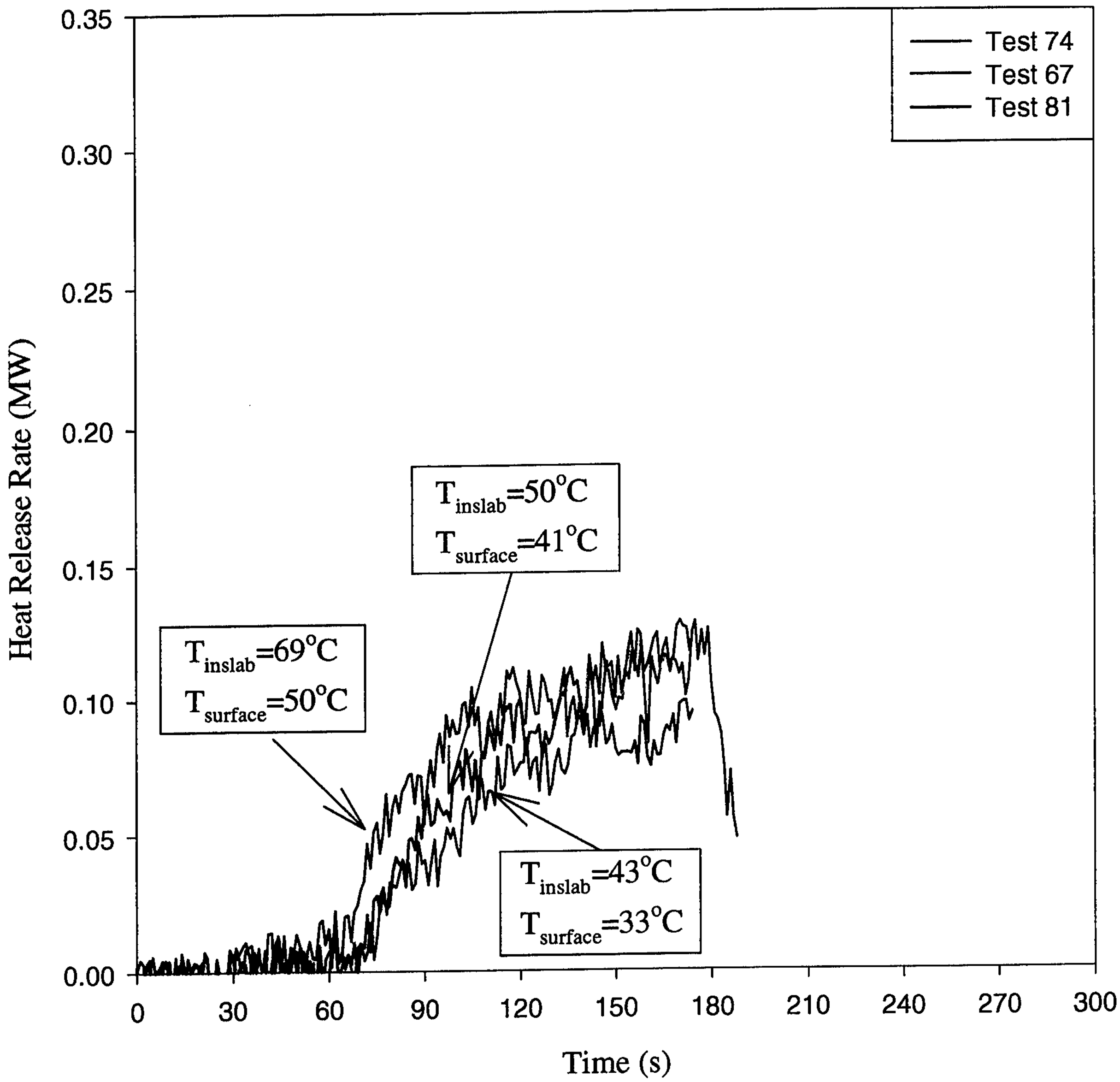


Fig. 17 – Comparison of heat release rates for JP-8 0.17 Lpm unconfined spill fires

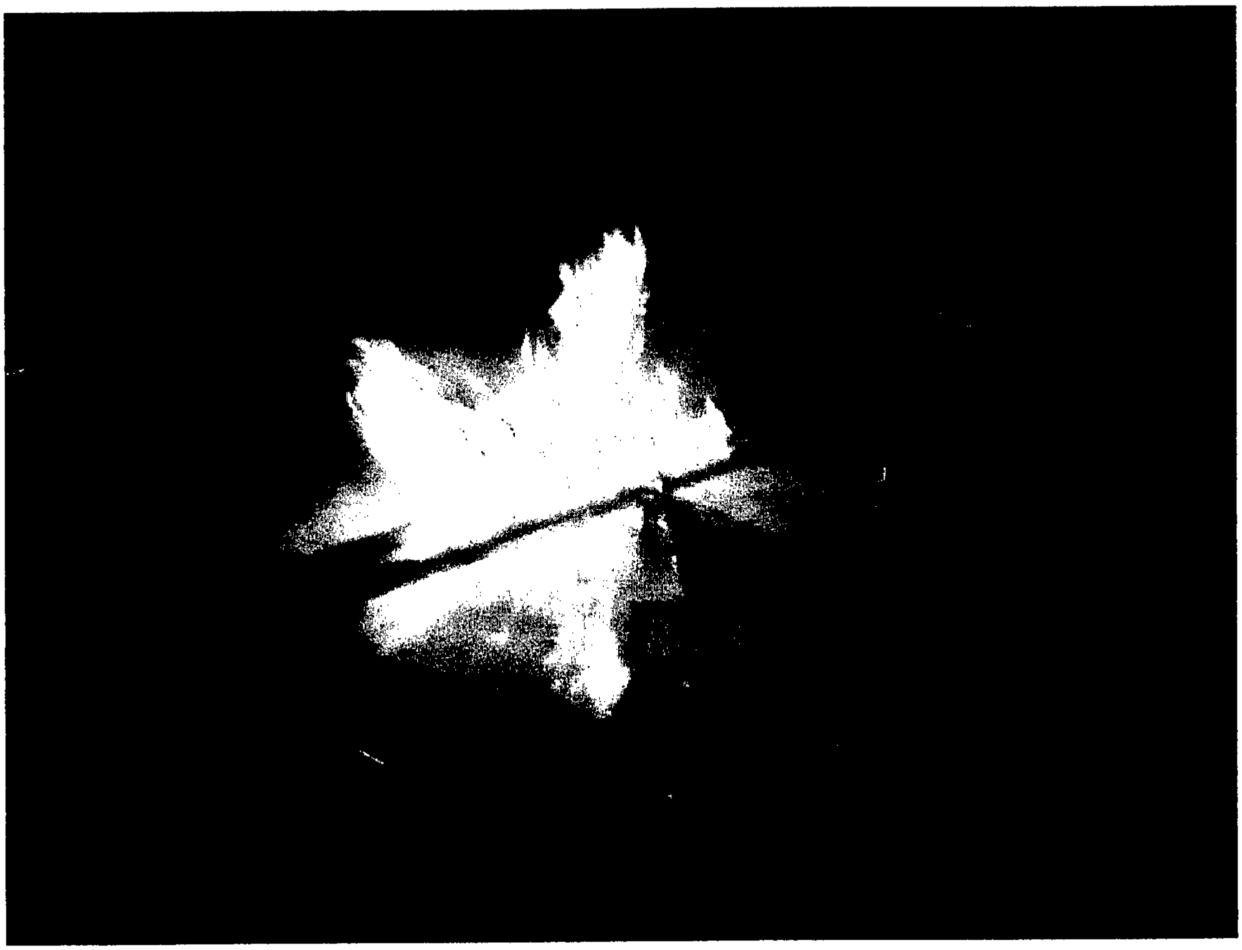


Fig. 18 – Photograph of a typical confined spill fire test (Test 33)

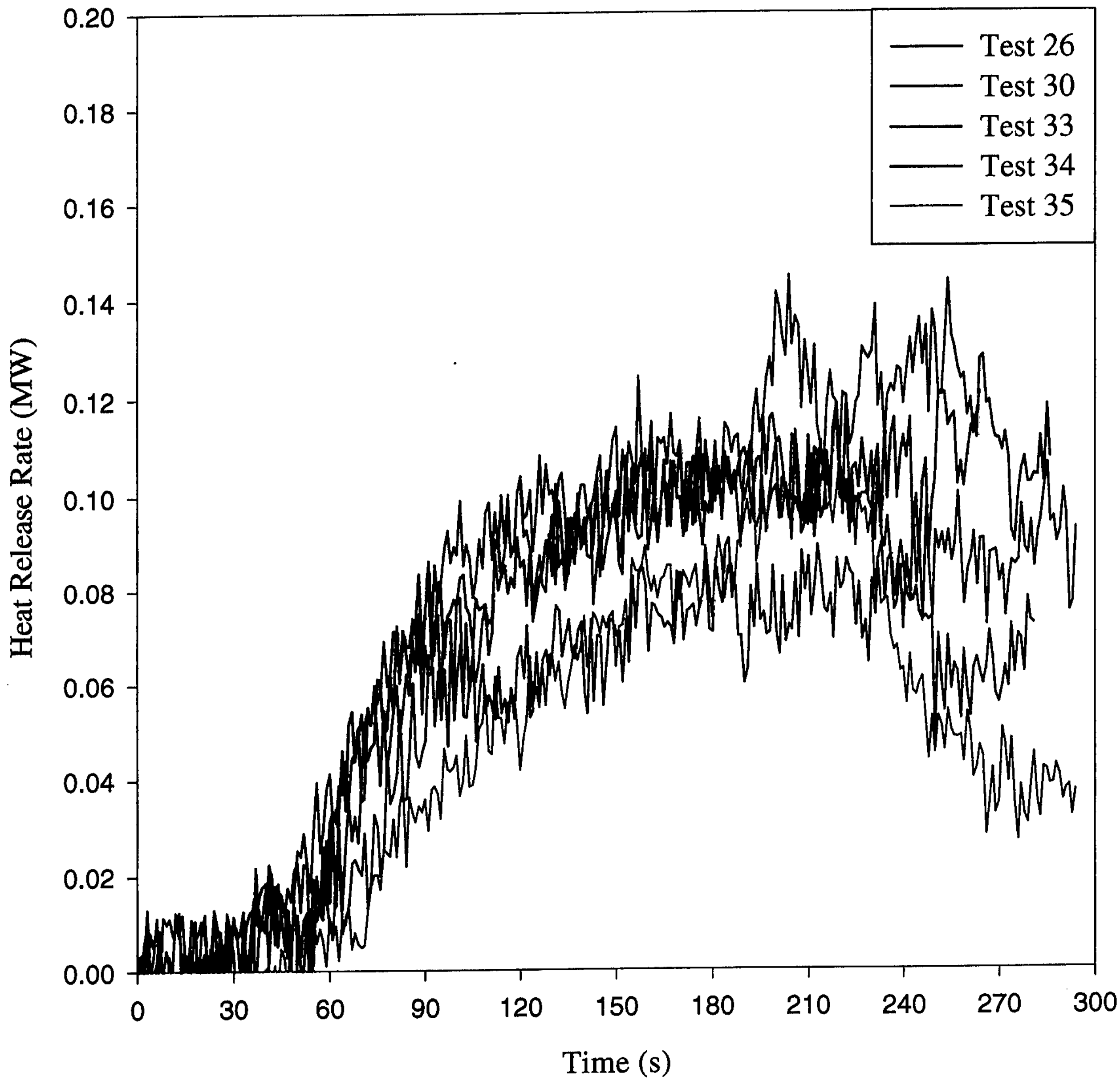


Fig. 19 – Comparison of heat release rates for 0.17 Lpm JP-8 spill fires confined in the y-direction (data has been adjusted so that time of ignition for all tests is at 60 seconds)

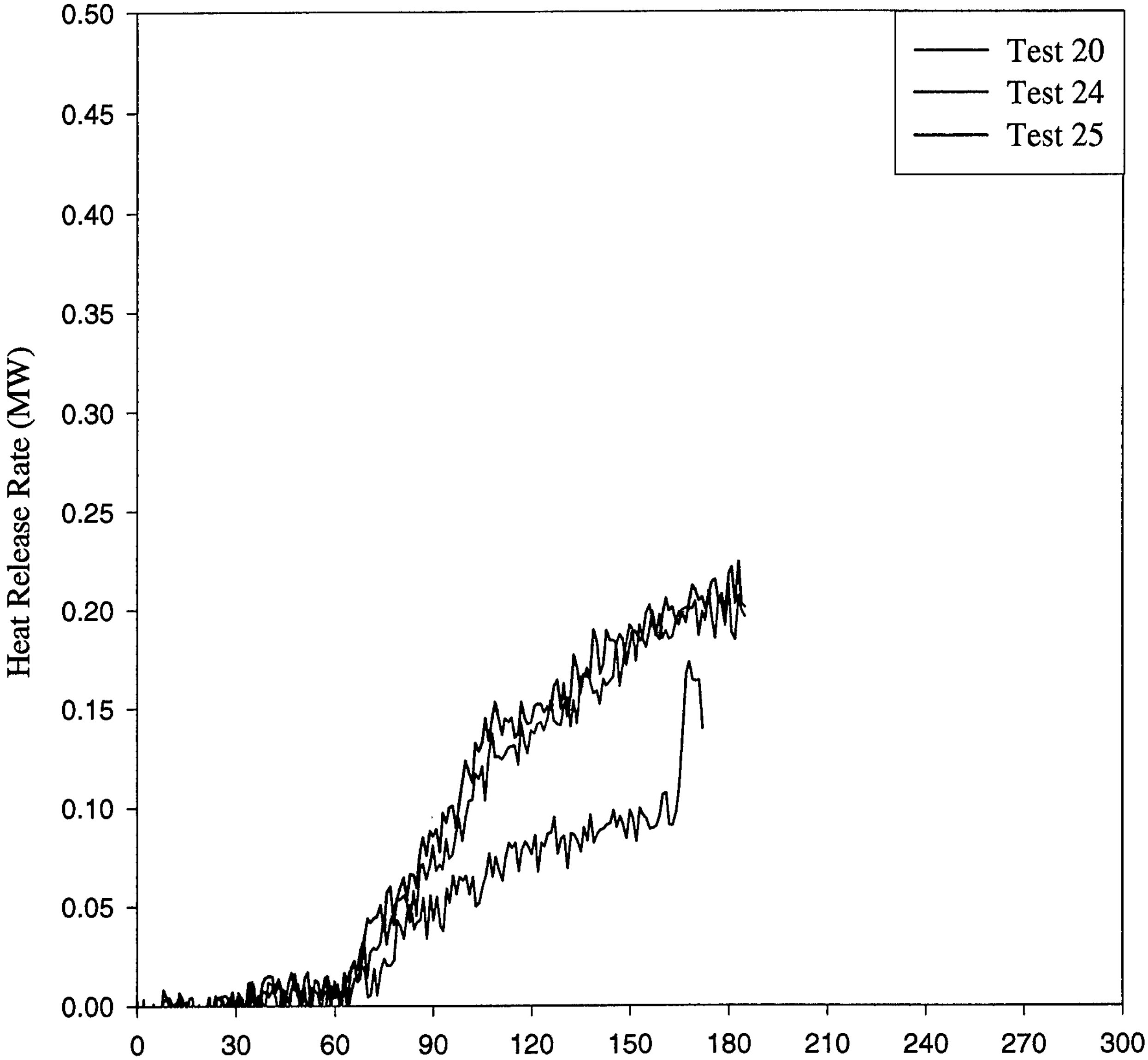


Fig. 20 – Comparison of heat release rates for 0.42 Lpm JP-8 spill fires confined in the x-direction

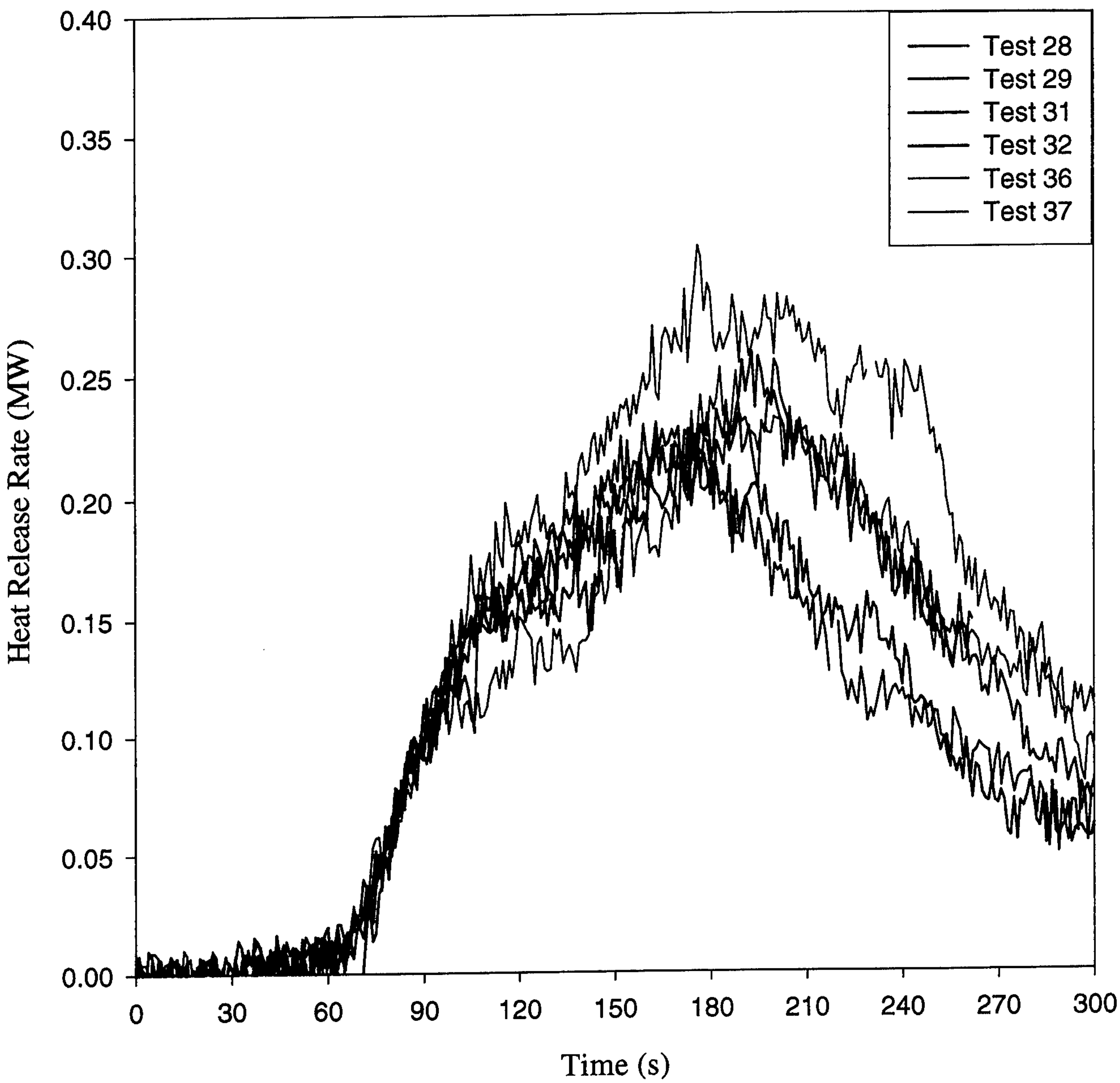


Fig. 21 – Comparison of heat release rates for 0.85 Lpm JP-8 spill fires confined in the y-direction

Table 12. Average Initial Temperature Measurements of the Fuel and Concrete Slab for the Three Confined Spill Fire Scenarios Presented in Figures 17, 18, and 19

Scenario	Test	Initial Fuel Temperature (°C)	In-slab Temperature (°C)
Scenarios 14-17			
0.17 Lpm (Y-dir)	26	26	42
	30	26	63
	33	26	68
	34	26	71
	35	22	40
Scenario 13			
0.42 Lpm (X-dir)	19	24	42
	20	24	41
	24	26	52
	25	26	59
Scenarios 14-17			
0.85 Lpm (Y-dir)	28	26	57
	29	27	60
	31	26	66
	32	26	68
	36	21	43
	37	22	49

state HRR values. One must also note in comparing heat release rate data for the confined spills that these fires are quite small (<200 kW) and therefore there is a higher uncertainty in the measurements (approximately ±10 percent). The differences between curves in Figure 19 are close to being within the uncertainty of the measurements.

The HRR curves for the 0.42 Lpm spill fires confined in the X direction (Figure 20) agree extremely well for Tests 24 and 25 which had concrete temperatures within 7°C (52 and 59°C). However, the HRR for Test 20 was significantly lower. The difference is attributed primarily to the position of the spill source; after Test 20 the spill was positioned consistently for all tests at +0.32 cm in the X-direction. Repositioning the spill location due to a high spot in the concrete resulted in the fire size being about twice as big as in Test 20 and 19. In Tests 24 and 25, the length of the fire was 2.7 m compared to 1.2 to 1.5 m for Tests 20 and 19, respectively. As discussed in Section 6.3.3 for fixed quantity spills, features of the concrete slab significantly influenced test results.

Figure 21 shows the comparison of the HRR curves for the 0.85 Lpm spill fires confined in the Y direction. For the first 100 seconds, the HRR data agree extremely well. After this time, the HRR starts to deviate up to 50 or 60 kW as the fires approach peak burning conditions at about 180 seconds. The temperature data in Table 12 shows that the maximum deviation in concrete temperatures between tests was 25°C. However, a comparison of the HRR curves and the temperature data reveals that the differences in HRR do not correspond to increasing temperature. For example, Test 36 had the lowest in-slab temperature at 43°C but resulted in the highest heat release rate. These results indicate that at the earlier stage of the fire where HRRs agree well, fire growth was primarily dependent on the fuel flow and temperature was not a factor. In the later stage of the fire, the temperature of the concrete is possibly more of a factor as the spill had already spread and heat transfer between the fuel and the concrete becomes important. But as noted, it is not clear why the heat release rates varied as they did.

6.3.3 Fixed Quantity Fuel Spill Fire Test

The fixed quantity fuel spill scenario was not as reproducible as the continuous unconfined spill. Figure 22 shows a photograph of a typical fixed quantity fuel spill fire test. Figure 23 shows the HRR curves versus time for the three 2 L fixed quantity spill tests. The peak HRR and the general growth rate of the fires were markedly different. Tests 10 and 11 reached peak HRRs of about 0.3 MW at 200 and 150 seconds, respectively. Test 99 reached a higher peak HRR of 1.1 MW in a shorter amount of time, at 110 seconds. Observations of these tests revealed that approximately one-half of the initial pool area of fuel did not burn for Tests 10 and 11, whereas in test 99, the entire pool burned.

This observation demonstrated one issue with conducting numerous spill fire tests on a concrete pad. Though the initial pad was level to within 3 mm over the entire surface, after being heated from repeat tests, the concrete pad developed several high spots which noticeably affected the shape and placement of the spill area on the pad. For instance, in test 99 the fuel was spilled

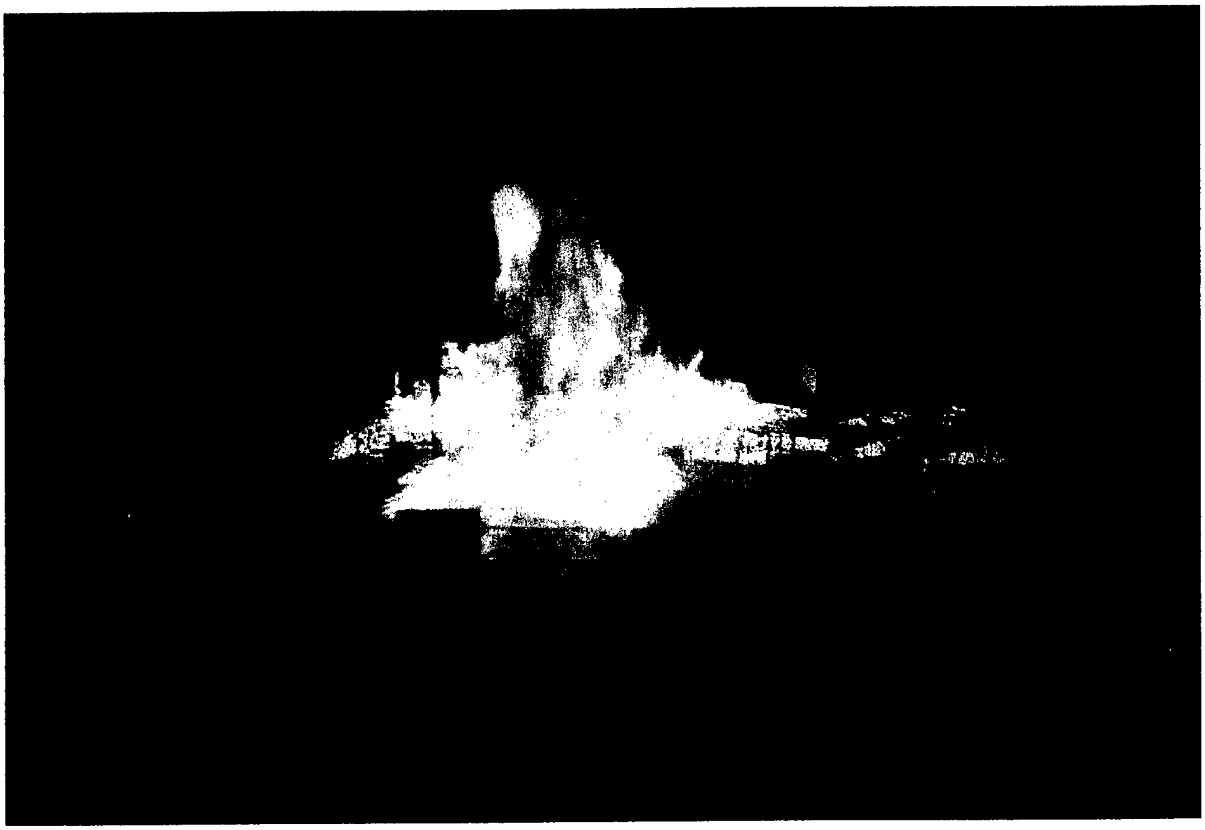


Fig. 22 – Photograph of a fixed quantity spill fire test (Test 9)

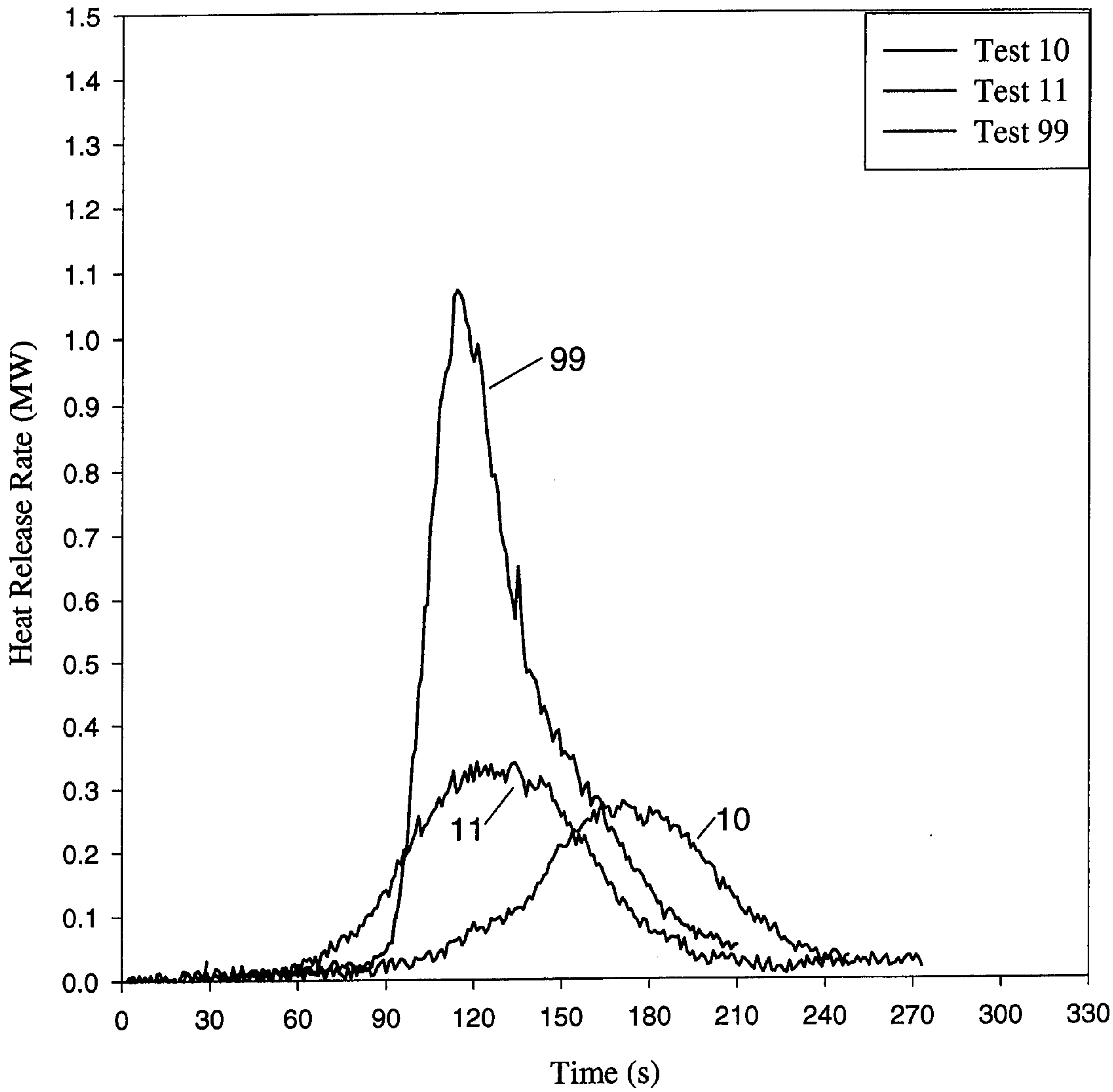


Fig. 23 – Comparison of heat release rates for 2 L fixed quantity JP-8 spill fires

at +22 cm in the x direction and along the center y axis, rather than at the original center of the pad (X = 0). This new spill location corresponded to the high spot on the pad. Spilling the fuel at this point yielded a more uniform circular spill pattern than the original center. The levelness of the concrete pad can influence the fire growth, particularly for spills that are ignited away from the source. For example, in Tests 10 and 11, the unevenness of the pool depth over the concrete slab prevented complete burning of the spill. This was further evidenced by the fact that the remaining spill area could not be manually ignited with the acetylene torch as was the initial pool.

Table 13 shows the initial spill area and fuel depth for Tests 10, 11, and 99. Also included in the table are the average temperatures of the fuel, the surface of the concrete pad and inside the concrete. The spill area was measured from video tape records and has an estimated uncertainty of less than 10 percent. The spill areas calculated from video also agree within 10% of the on-site observed measurements. The average spill depth was calculated based on the spill volume and the measured spill area. The initial spill depth increases from Test 10 to 11 to 99 on the order of 11 and 17 percent, respectively. There is not sufficient data to determine whether the difference in the average spill depth is meaningful with respect to fire growth. However, the depth is small compared to minimum required depths for flame spread reported in the literature (1.5 mm) [14]. The fact that the fires of Tests 10 and 11 did not burn to completion indicates that localized spill depth and surface features influence the growth of the fire.

Table 13. Average Initial Spill Size and Temperature Measurements of the Fuel and Concrete Slab for the 2 L Fixed Quantity Spill Fire Tests

Test	Spill Area (m^2)	Pool Depth (mm)	Initial Fuel Temperature (°C)	In-slab Temperature (°C)	Slab Surface Temperature (°C)
10	2.7	0.73	22	40	31
11	2.5	0.81	21	40	30
99	2.1	0.95	22	57	43

Besides the issue of spill depth/geometry, Tests 10, 11 and 99 also demonstrate that the temperature of the concrete pad can also influence the fire growth. Table 13 shows that the initial fuel temperature for each test was the same (21-22°C). However, the concrete temperature was substantially higher (13 to 17°C) for Test 99 compared to Tests 10 and 11, which were the same. As seen in Figure 23, the higher temperature of the slab in Test 99 resulted in the fire spreading more quickly (shown by the steep rise in the HRR).

The effect of temperature is also seen in the 3 L fixed quantity spill fire tests. Figure 24 shows the HRR curves for the six 3 L fixed quantity tests. The corresponding temperature and initial spill size measurements are presented in Table 14. Again, Tests 12, 11 and 113 are

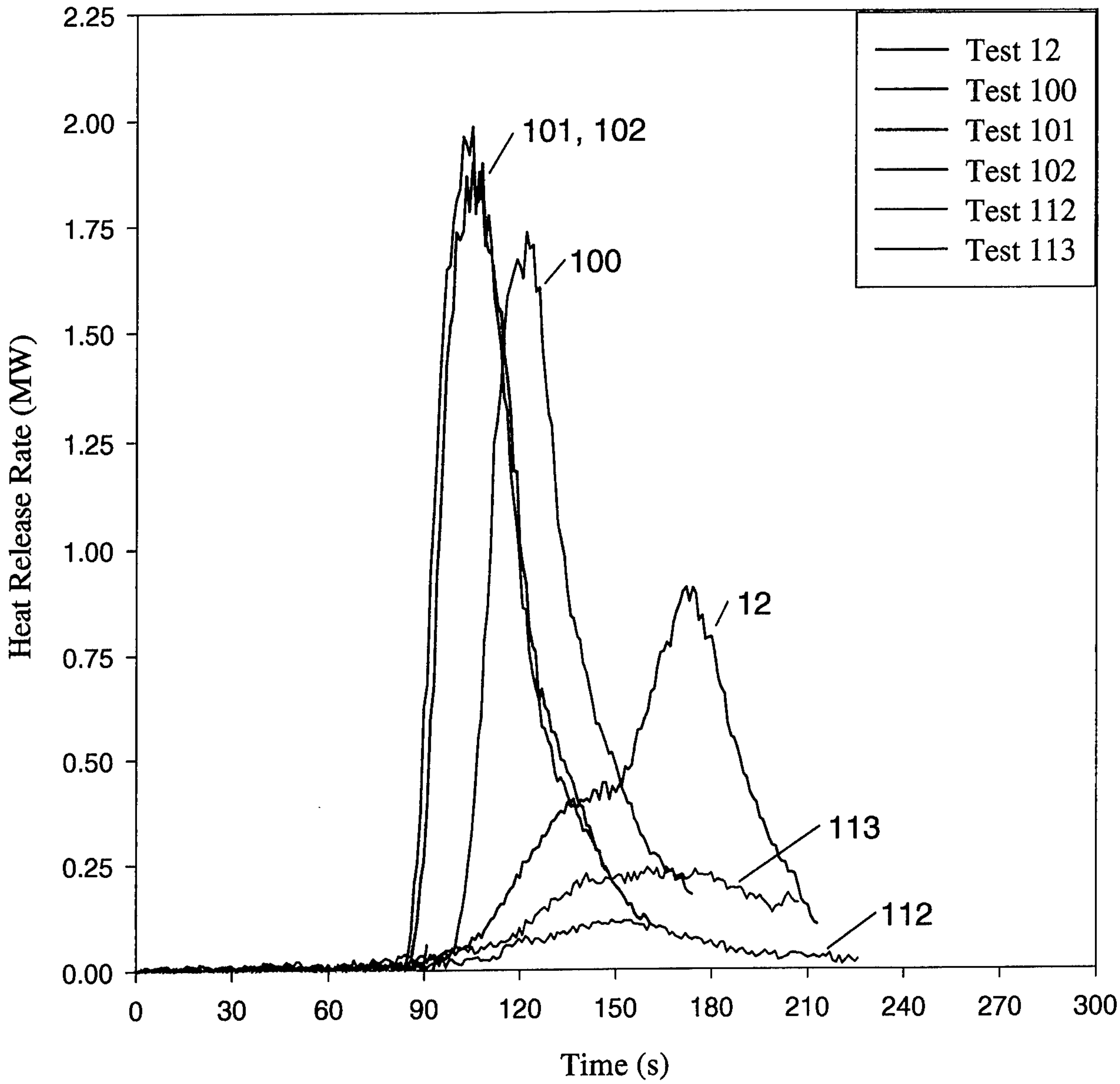


Fig. 24 – Comparison of heat release rates for 3 L fixed quantity JP-8 spill fires

representative of spills which did not burn completely due to the pool geometry, resulting in a slower fire growth rate and a lower peak HRR. Tests 112 and 113 were poured at the same location as Tests 100-102; therefore, the spill geometry should have been the same. Table 14 shows that the initial spill size and average fuel depth was approximately the same for all tests. The HRR measurements of Tests 112 and 113 are also low compared to test 12 because most of the fire effluent was not captured by the hood as it was in the other tests (mainly due to the location of the fire on the pad with respect to the hood). Tests 100-102 had fairly uniform circular shapes and burned completely. For Tests 100-102, both the initial fuel temperature and the concrete slab temperatures (inside and surface) increased with subsequent tests to the point that they were greater than the full flash point of 52°C. The temperature effect was evident in the fire growth rate. For Test 100, the fire spread rapidly after the first 0.3 to 0.6 m, at which time flamelets (and a ghosting blue flame) flashed out over the vapor layer above the spill. Full fire involvement of the spill occurred in 20 seconds for Test 100. In Tests 101 and 102, the flame spread was noticeably faster. The flame rapidly spread across the surface, immediately as the fuel was ignited. Full involvement of the spill occurred in 2 seconds for Tests 101 and 102 compared to 20 seconds for Test 100. This difference in fire growth times is reflected in the HRR curves of Figure 24.

Table 14. Average Temperature Measurements of the Fuel and Concrete Slab for the 3 L Fixed Quantity Spill Fire Tests

Test	Spill Area (m^2)	Pool Depth (mm)	Initial Fuel Temperature (°C)	In-slab Temperature (°C)	Slab Surface Temperature (°C)
12	3.0	1.0	22	39	29
100	2.8	1.1	N/A	59	46
101	3.1	0.96	38	61	50
102	3.0	1.0	54	64	48
112	2.8	1.1	29	36	32
113	2.9	1.0	29	36	32

Based on these results, the fixed quantity spill fire scenario is dependent on the physical structure of the surface (i.e., levelness, surface coating, porosity, surface roughness) and the temperature of the surface as well as the fuel. Although a systematic study of surface features was not undertaken in this program, it is evident from the results that surface features which will impact pool shape and depth will have a significant effect on fire growth rate and ultimate size. Contrary to the continuously flowing unconfined spill scenarios, temperature variations have a direct effect on fire growth rate and size. When fixed quantity spill fire tests are conducted, special attention must be given to maintaining uniform surface features and temperatures to assure repeatability.

6.3.4 Repeatability in Pan Fire Tests

Figure 25 shows a photograph of a pan fire test. A comparison of the heat release rate curves for the 0.6 x 0.6 m JP-8 pan fire tests is presented in Figure 26. The HRR data agrees well between tests, signifying good repeatability. The HRR curves of the larger 0.9 m diameter pan fires do not agree as well as the 0.6 x 0.6 m pan fires (Figure 27). However, the fire growth rate during development and the final steady-state values are generally in good agreement. The primary difference is in the delay in the initial growth and the transition to steady-state. These differences can be significant since detector response is expected during the time that the differences exist. Therefore, if OFD response is dependent on fire size, there could be significant differences in alarm times on the order of 20 seconds or more. Based on the HRR data, the pan fires do not appear to be more repeatable than the 1.7 Lpm unconfined spill fire tests.

6.3.5 Summary: Fire Test Repeatability With Respect to HRR

The unconfined spill, confined spill, and pan fire tests can be conducted with good repeatability. Maintaining repeatability of fixed quantity spill scenarios can be done but is more difficult to achieve than the other scenarios. The pan fires do not appear to be more repeatable than the 1.7 Lpm unconfined spill fire tests. For the fixed quantity spill fire tests, the physical structure of the surface (e.g., levelness, coating, porosity, roughness) can impact the spill and fire growth. Concrete and fuel temperatures directly effected the fire growth rate and size of the fixed quantity spill fires. For the unconfined spill fires, the concrete temperature had a minor effect on fire growth, with the effect being largest for the smaller flow rates.

6.4 OFD Performance with respect to Fire Size

In general, all OFDs performed better with increasing fire size for the scenarios studied. It is noted that fires exceeding 1 MW may result in different black body-type source radiation emissions, which could have a negative effect with some multi-spectrum IR detectors. Whether this is true or not with the currently available models was not investigated. The fires of this study did not exceed 1 MW. Better performance means that OFD models were able to detect a fire at farther distances and at more orientations (e.g., horizontal off-axis), and it also can mean that OFD response time was shortened.

A summary of the effect on OFD performance due to fire size is presented in Table 15 for six test scenarios. For the unconfined JP-8 spill fires, larger fires resulted in more OFD alarms and shorter times to alarm. The same general conclusion is reached with the fixed quantity spill fires and the pan fires. With the confined fires, there was an improvement in some OFD models with increasing fire size, but overall there was little to no difference.

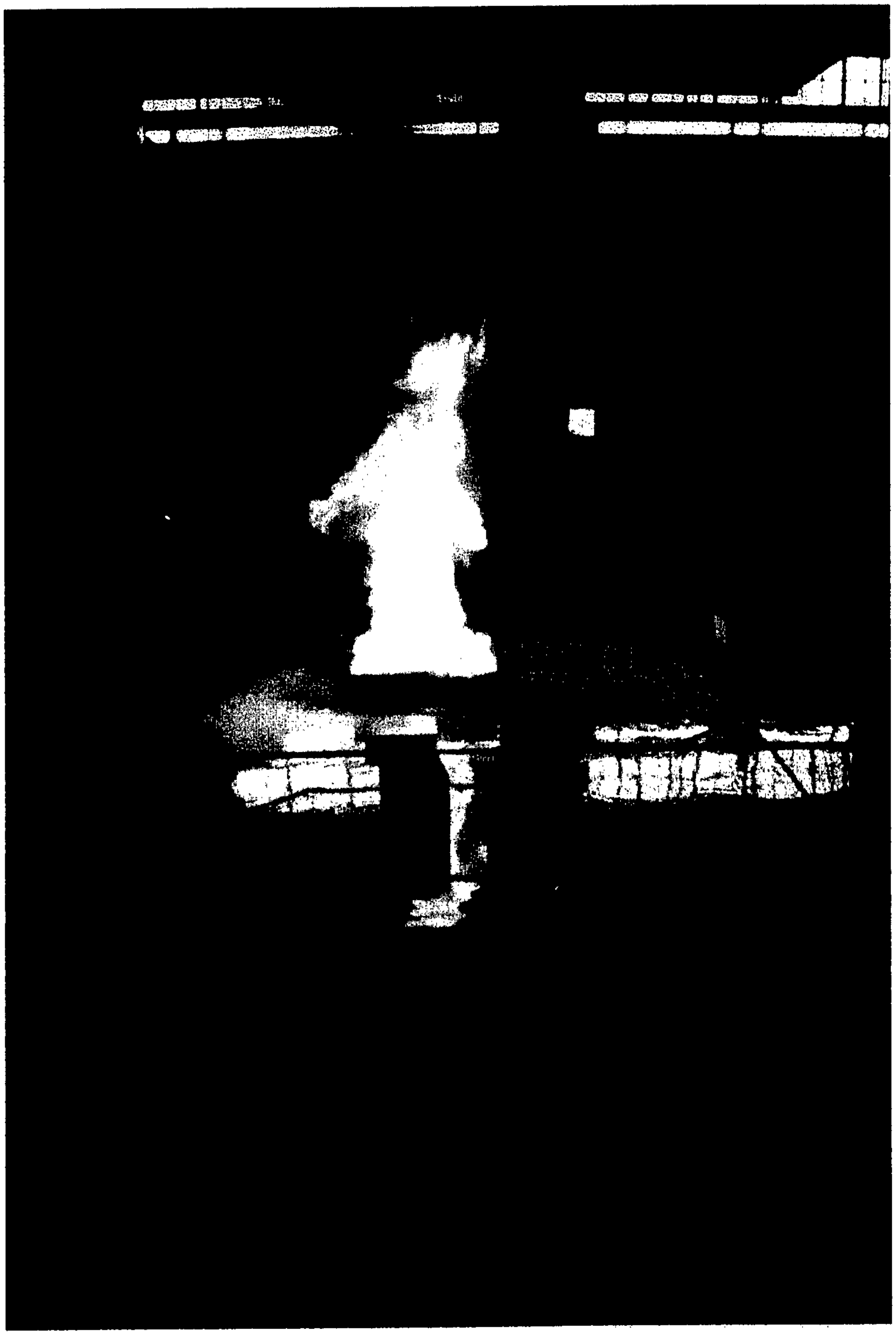


Fig. 25 – Photograph of a pan fire test (Test 13)

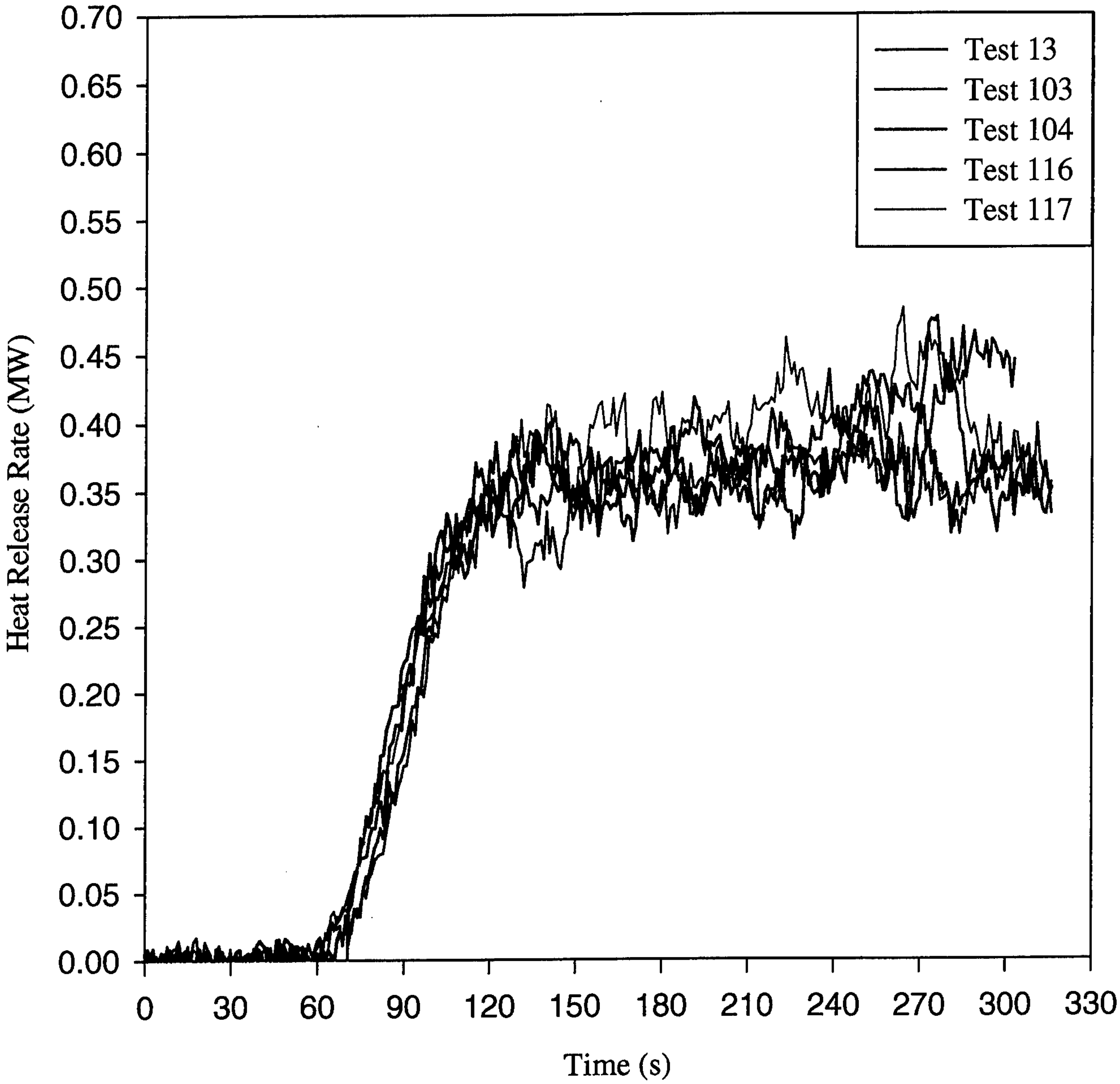


Fig. 26 – Comparison of heat release rates for 0.6 x 0.6 m JP-8 pan fires

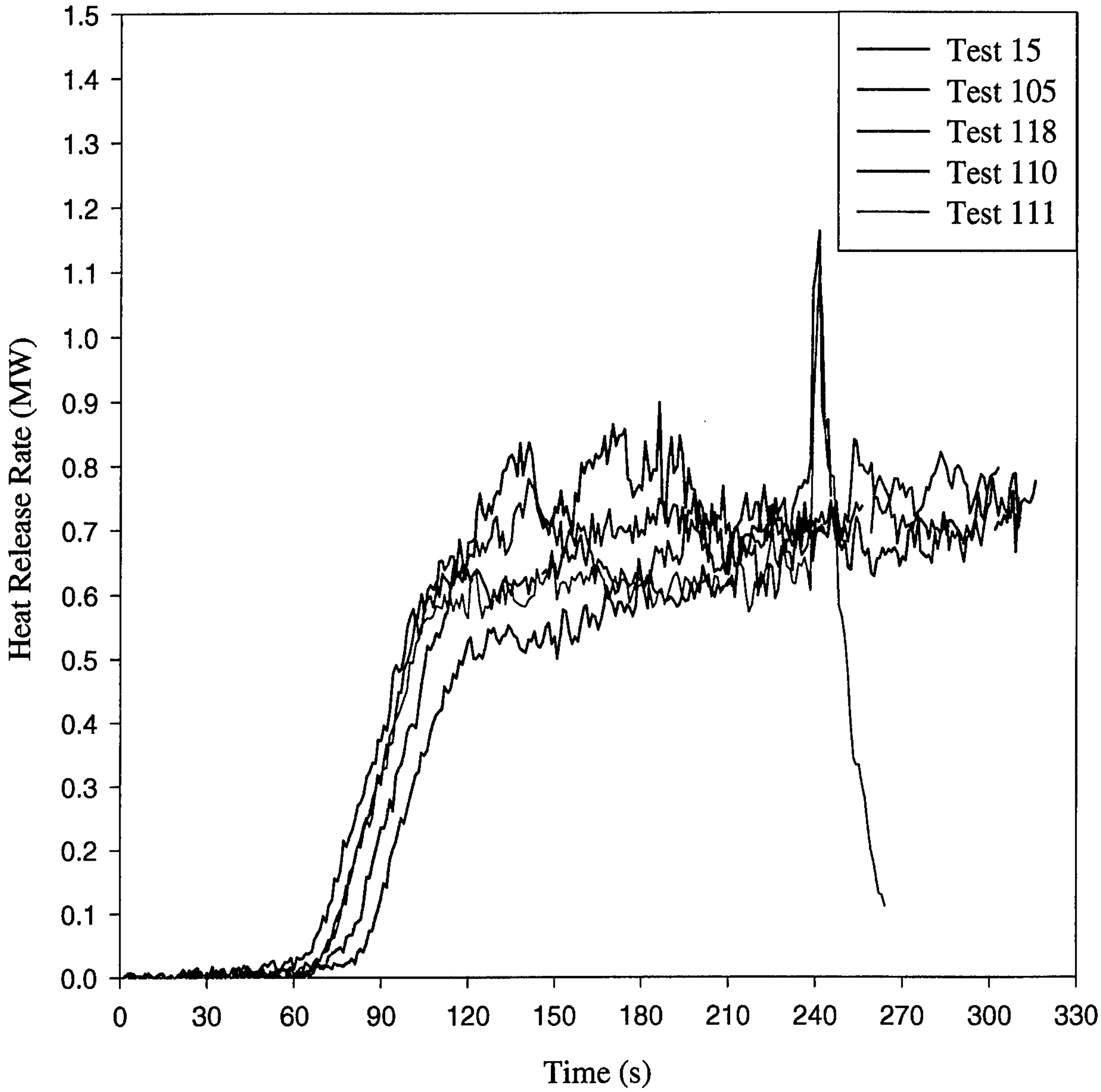


Fig. 27 – Comparison of heat release rates for 0.91 m diameter JP-8 pan fires

Table 15. Summary of OFD Performance with Respect to Fire Size for Six Test Scenarios *

Scenario	OFD1	OFD2	OFD3	OFD4	OFD5	OFD6
Scenario 1 JP-8 Unconfined 1.7 vs. 0.17 Lpm	More alarms: 1.7 - all alarmed; 0.17- all 31 m, and 46 DLS	More alarms: 1.7 - 31 m DLS only; 0.17 no alarms	More alarms: 1.7 - all alarmed; 0.17- all 31 m, and 46 m DLS	More alarms: 1.7 all but one test at 46 m HVOA; 0.17 - no alarms	More alarms: 1.7 - 31 m DLS only; 0.17 no alarms	Same: All units alarmed for both (shorter times for 1.7)
Scenario 12 JP-8 Fixed Quantity 3 vs. 1 L	More alarms: 3 - all except 1/4 of tests at 46 m HVOA; 1 - all 31 m, and 46 m DLS	Few more alarms: 3 - only 1/4 tests at 31 m DLS; 1 - no alarms	More alarms: 3 - all except 1/4 of tests at 46 m HVOA; 1 - all 31 m, and 46 m DLS and HVOA	More alarms: 3 - all alarmed; 1 - all 31 m	Few more alarms: 3 - only 31 m DLS; 1 - no alarms	Same: All units alarmed for both
Scenario 13 JP-8 Confined X-direction 0.85 vs. 0.17 Lpm	Few more alarms with 0.85	Same: No alarms for either	Few more alarms with 0.85	More alarms: 0.85 - some 31 m DLS; 0.17 no alarms	Same: No alarms for either	Same: All units alarmed for both (shorter times for 46 m off-axis)
Scenario 14 JP-8 Confined Y-direction 1.7 vs. 017 Lpm	More alarms: 1.7 - all 31 m and some 46 m; 0.17 no alarms	Same: No alarms for either	Same: Alarmed for all 31 m and 46 m DLS (shorter times for 1.7)	More alarms: 1.7 - some 31 m alarms; 0.17 no alarms	Same: No alarms for either	Same: Alarmed for all (small if any decrease in alarm times at 46 m)
Scenario 18 JP-8 Pan 0.9 m dia. vs. 0.3 x 0.3 m	More alarms: 0.9 - all 31 m, 46 m DLS and ½ HVOA; 0.3 - no alarms	More alarms: 0.9 - all 31 m DLS; 0.3 - no alarms	More alarms: 0.9 - all except ½ at 46 m HVOA; 0.3 - all 31 m, and 46 m DLS (shorter alarm times by 30-40 s)	More alarms: 0.9 - all alarmed; 0.3 - no alarms	More alarms: 0.9 - 31 m DLS and ½ tests at 46 m DLS; 0.3 - no alarms	Same: All units alarmed for both (shorter alarm times by 20-30 s)
Scenario 19 JP-5 Unconfined 0.17 vs. 1.7 Lpm	More alarms: 1.7 - all alarmed; 0.17 - 2/3 tests at 31 m DLS and HVOA	Few more alarms: 1.7 - 1/4 tests at 31 m DLS; 0.17 - no alarms	More alarms: 1.7 - all except 1 test at 46 m HVOA; 0.17 - all 31 m, and 46 m DLS (1.7, alarm times similar or slightly shorter)	More alarms: 1.7 - all except 1 test at 46 m HOA; 0.17 - no alarms	Few more alarms: 1.7 - only 31 m DLS; 0.17 - no alarms	Same/fewer: 1.7 - all except 1 test at 31 m DLS & HOA; 0.17 - all alarmed (1.7 slightly longer alarm times, <10 s)

* "More alarms" indicates that more alarms were recorded for the larger fire size. "Same" indicates that the same alarms were recorded for both fire sizes

6.5 Repeatability in OFD Performance

An analysis of the repeatability of individual OFD response was performed. The analysis consisted of evaluating the data presented in Appendix C, which shows the individual detection response times and heat release rates (HRR) at the time of alarm for each detector and test. This data was considered while reviewing the HRR plots presented in Appendix D for each test fire.

The main conclusions to be drawn from this study with regards to repeatability in OFD performance are as follows:

1) For similar test scenarios (i.e., reproducible heat release rate curves), OFD responses were quite repeatable. That is, the same OFDs alarmed for each test and the response times for those OFDs were close (within 10 seconds). Several examples include Tests 7 and 8; Tests 3, 4, 76 and 77; and Tests 5, 6, 78 and 79. The standard deviations of the alarm times for the later two examples are less than 5 seconds.
2) If the heat release rate curves vary in time between tests, than the OFD alarm times typically vary accordingly. In other words, the alarm times correspond well to fire size. If fire A grows more slowly than fire B, than OFDs will alarm slower for fire A than fire B, for example compare Test 52 with Tests 53 and 54.
3) Although variations in HRR or fire growth may effect the alarm times of individual detectors, these variations typically do not affect whether OFDs alarm or do not alarm from test to test of the same scenario. Examples include Tests 26 and 30, and Tests 52, 53 and 54.

6.6 OFD Response to Fires with Optical Sources/Obstructions in Field of View

Section 5.4 describes various optical sources (potential nuisance sources) and obstructions that were placed within the field of view of the detectors during some of the fire tests. Table 5 shows which tests were conducted for each of the combined scenarios. The main objective of these combined test scenarios was to determine whether the inclusion of potential nuisance sources and obstructions within a detector field of view can impede or prevent the detector from identifying an alarm condition with a real fire. The following sections discuss the results of these tests and the usefulness of including such scenarios in a performance specification.

6.6.1 Chopped UV/IR

The chopped UV/IR source was included with JP-8 unconfined spill fires (Scenario 2) and JP-8 spill fires confined in the Y direction (Scenario 15). A comparison of the OFD results for the Scenario 2 and 15 tests revealed the following:

1) The chopped UV/IR source prevented OFD1 from alarming at 31 m DLS and off-axis positions for 100 kW fires and at 96 m off-axis positions for 1000 kW fires.

OFD 2 (UV/IR) did not alarm with the UV/IR source at 31 m DLS for 1000 kW fires.

2) The chopped UV/IR source had no effect on the alarm responses from OFD5 (UV/IR), OFD4 (2-IR), and OFD 3 and 6 (3-IR).
3) The source had no significant effect on the alarm times from the detectors which responded to the fires.

The use of the chopped UV/IR source did provide a means of discriminating between detector performance.

6.6.2 Chopped IR at 20 m

The chopped IR source at 20 m was included with JP-8 unconfined spill fires (Scenario 3) and JP-8 spill fires confined in the Y direction (Scenario 16). A comparison of the OFD results for the Scenario 3 and 16 tests revealed the following:

1) The chopped IR source prevented OFD3 (3-IR) from alarming at 31 m off-axis (only for 100 kW fires, no effect for 1000 kW fires). With the 1000 kW fires (1.7 Lpm), the alarm times were 10 to 25 seconds slower with the IR source (e.g., 54 s compared to 30 s).
2) The chopped IR source prevented OFD4 (2-IR) from alarming at 31 m off-axis (i.e., OFD near source) for 1000 kW fires. The alarm times were approximately 30 seconds slower with the IR source in the detector field of view.
3) The chopped IR source prevented OFD2 (UV/IR) from alarming for the 1000 kW fires (OFD 2 did not alarm for the 100 kW fire with or without the IR source).
4) Other OFDs were unaffected.

6.6.3 Chopped IR at 26 m

The chopped IR source at 26 m was included with JP-8 unconfined spill fires (Scenario 4) and JP-8 spill fires confined in the Y direction (Scenario 17). A comparison of the OFD results for the Scenario 4 and 17 tests revealed the following:

1) The chopped IR source prevented OFD 1 (UV/IR) and OFD 3 (3-IR) from alarming at 31 m locations for 100 kW fires.
2) The chopped IR source prevented OFD1 (UV/IR), OFD2 (UV/IR), OFD3 (3-IR), and OFD4 (2-IR) from alarming at several locations for the 1000 kW fire.
3) The IR source caused additional alarms for OFD5 (UV/IR) for both the 100 and 1000 kW fires.
4) OFD6 (3-IR) was unaffected by the source.
5) There was no significant differences in alarm times except for OFD4 (2-IR) which was 23 seconds slower at the 46 m DLS position.

The two chopped IR sources were useful for discriminating between detector performance.

6.6.4 Doors Open and Lights On

This test variation was conducted with JP-8 unconfined spill fires (Scenario 11). A comparison of the OFD results for the Scenario 11 tests revealed the following:

1) The additional light had little to no effect on OFD responses.
2) Alarm times may be faster by 10 to 20 seconds, but the difference could be due to a slightly sooner rise in the HRR.
3) Based on these results, there is no apparent reason to include such a test in a performance specification. Another source of light that may warrant investigation include reflected sun light.

6.6.5 Arc welding at 15 m

Arc welding at 15 m was conducted with JP-8 unconfined spill fires (Scenario 9). A comparison of the OFD results for the Scenario 9 tests revealed the following:

1) The arc welding prevented OFD1 (UV/IR) from alarming at multiple 31 m positions with the 100 kW fires but it had no effect on the detector with 1000 kW fires (OFD1 alarmed at all locations).
2) The arc welding prevented OFD2 (UV/IR) from alarming. OFD2 only alarmed for the 1000 kW fire at 31 m DLS without the welding source.
3) The welding had no effect on the other OFDs.
4) Alarm times were the same or slightly faster (5-20 s) with the welding source. The increase in time may be partially due to the fires growing at a slightly earlier time for the tests with the arc welding.

6.6.6 Arc Welding at 27 m

Arc welding at 27 m was conducted with JP-8 unconfined spill fires (Scenario 10). A comparison of the OFD results for the Scenario 10 tests revealed the following:

1) The arc welding prevented OFD2 (UV/IR) from alarming. OFD2 only alarmed for the 1000 kW fire time at 31 m DLS without the welding source.
2) The welding at 27 m had no effect on the other OFDs.
3) The alarm times were approximately the same or slightly faster (<15 s) with arc welding in the view of the detectors.

The arc welding at 27 m had a lesser adverse effect on detector performance than did the welding at 15 m. This is attributed to the fact that the 27 m welding source was at about 37 degrees off-axis to the detector direct line of sight compared to 11 degrees for the 15 m location. Consequently, the 27 m source, though closer, was actually more on the outer limites of the field of view of the detectors than the source at 15 m. Overall, the inclusion of an arc welding source with a fire provided useful information of how well detectors can discriminate between nuisance sources and real fires while also detecting real fires. The source created more challenging conditions for detection, particularly with smaller fires.

6.6.7 0-1.34 m obstruction

A 0-1.34 m high obstruction was placed in front of 1000 kW, JP-8 unconfined spill fires (Scenario 5). A comparison of the OFD results for the Scenario 5 tests revealed the following:

1) The obstruction prevented OFD1, 2, and 5 (all UV/IR) from alarming. OFD1 had alarmed at all locations without the obstruction and OFD2 and 5 had alarmed at 31 m DLS.
2) The obstruction prevented a few OFD4 (2-IR) alarms at 41 m off-axis.
3) There was no effect on OFD3 and OFD6 (both 3-IR). OFD6 alarmed at all locations. OFD3 alarmed at all locations except for one test at several 41 m off-axis, both with and without the obstruction.
4) OFD3 and 6 (3-IR) had slower alarm times (~10 s) with the obstruction.

6.6.8 Moving 0-1.34 m Obstruction

A number of tests were conducted in which the 0-1.34 m high obstruction was rapidly moved out of the view of the detector, 60 seconds after the fire was initiated. This moving obstruction scenario was conducted with 1000 kW, JP-8 unconfined spill fires (Scenario 6). A comparison of the OFD results for the Scenario 6 tests revealed the following:

1) Moving the obstruction allowed OFD1 (UV/IR) to alarm at most positions, but there were still fewer alarms than without the obstruction. OFD1 did not alarm during one of the two tests at 46 m HOA.
2) Moving the obstruction had no effect on the other OFDs. The results were the same as for the tests with the stationary obstruction.

The tests with the moving obstruction provided little additional insights than the stationary obstruction tests.

6.6.9 0.3-2.3 m Obstruction

A 0.3 to 2.3 m high obstruction was placed in front of 1000 kW, JP-8 unconfined spill fires (Scenario 7). A comparison of the OFD results for the Scenario 7 tests revealed the following:

1) With a 250 kW fire (0.42 Lpm), the obstruction prevented all OFDs from alarming, except OFD6 (3-IR) at 31 m DLS and some HVOA.
2) With a 1000 kW fire (1.7 Lpm),
    a) The obstruction prevented off-axis alarms for OFD1 (UV/IR), OFD3 (3-IR), and OFD4 (2-IR)
    b) The obstruction prevented all OFD2 and 5 (UV/IR) alarms (detectors alarmed at 31 m DLS without the obstruction)
    c) OFD6 (3-IR) alarmed for all tests at all locations. The alarm times were approximately 13 s longer with the obstruction.

The raised obstruction provided a larger challenge to detection than did the 0-1.3 m high obstruction. The 0.3-2.3 m obstruction tests resulted in fewer alarms and longer alarm times for some detectors that did respond.

6.6.10 Moving 0.3-2.3 m Obstruction

A number of tests were conducted in which the 0.3-2.3 m high obstruction was rapidly moved out of the view of the detector, 60 seconds after the fire was initiated. This moving obstruction scenario was conducted with 1000 kW, JP-8 unconfined spill fires (Scenario 8). A comparison of the OFD results for the Scenario 8 tests revealed the following:

1) Upon moving the obstruction, OFD1 (UV/IR) and OFD4 (2-IR) had additional alarms at 46 m off-axis positions, yielding the same results as without the obstruction.
2) Upon moving the obstruction, OFD5 (UV/IR) alarmed at 31 m DLS, yielding the same results as without the obstruction.

Moving the obstructions provided little additional insight than obtained with the tests with the stationary obstruction. The moving obstruction test is not recommended as part of a test specification. However, since stationary obstructions in front of a fire are plausible hangar fire scenarios and these scenarios do provide a means of evaluating the limits of OFD detection performance, the inclusion of obstructed fire tests in a performance specification is recommended. Based on this testing, the raised obstruction was slightly more challenging than the obstruction that covered the base of the fire.

6.6.11 Summary of Test Variations

The main objective of incorporating various optical sources and obstructions was to assess whether these sources would prevent detectors from properly responding to real fires. Based on the results of this test program, most of the sources and the obstruction scenarios proved to be useful in identifying limitations and weaknesses in some of the detectors. Table 16 summarizes the usefulness of incorporating the various optical sources and obstructions into the fire tests of a performance specification.

Table 16. Summary of Usefulness of the Optical Sources and Obstruction Test Scenarios

Test Scenario	Result
Chopped UV/IR	Useful Test
Chopped IR	Useful Test
Doors/lights on	Unnecessary
Arc Welding	Useful Test
Obstruction	Useful Test (recommend raised obstructions)
Moving Obstruction	Unnecessary

6.7 OFD Response to False Alarm Sources

As described in Section 5.4, the detectors were exposed to a number of potential false alarm sources to determine if the OFDs would alarm and to establish a baseline for the optical sources used along with the fire sources. The optical stress sources (i.e., potential false alarm sources) used during the fire tests were set up to provide an additional source within the field of view of the detector without causing an alarm signal.

Table 17 presents a summary of the OFD responses to the false alarm sources conducted without a fire. The table includes the false alarm test number, a description of the source, and comments on detector responses. In addition to the sources described in Section 5.4 and used during the fire tests, Table 17 presents several other false alarm sources that were evaluated. These additional tests included flashes from cameras and attempts at blowing bulbs.

Table 17. Summary of OFD Responses to Potential False Alarm Sources

Test No.	Source Description	OFD Responses
False001	Chopped UV/IR (halogen lamps) at 20 m	No Alarms All OFD1 (UV/IR) indicated a UV or IR warning All OFD2 (UV/IR) indicated a UV warning
False002	Chopped IR (quartz heater) at 20 m	No Alarms
False003	Chopped IR (quartz heater) at 20 m with random walking between source and OFDs	No Alarms except OFD6 (3-IR) at 31 m, DLS
	then with camera flashes at various locations within 10 m of OFDs	No Alarms
	then with quartz flash within 9 m and then 2 m of OFDs	No Alarms
False004	No available data	No available data
False005	Chopped IR (quartz heater) at 26 m	No Alarms OFD2 (UV/IR) at 31 m, HOA in IR warning
False006	Chopped UV/IR (halogen lamps) at 26 m	No Alarms
False007	Halogen lamp (500 W) without cover Bulb shot with pellet gun	No Alarms
False008	Halogen lamp (500 W) without cover started with 3 drops of multipurpose oil on bulb	No Alarms
	then started with a spot of black spray paint on bulb	All OFD1 (UV/IR) in UV or IR warning during initial lighting with oil
	then bulb shot with pellet gun (smoked and burned out)	All three OFD2 at 30 m in UV warning during initial lighting with oil

Table 17. Summary of OFD Responses to Potential False Alarm Sources (Continued)

Test No.	Source Description	OFD Responses
False009	Halogen lamp (500 W) with glass relief tip on bulb broken off then bulb blown via shot from pellet gun	No Alarms
False010	Arc welding at 15 m	No Alarms All OFD1 and OFD2 (both UV/IR) in UV warning
False011	Chopped IR (quartz heater) at 26 m and 150 W incandescent bulb - 46 s, bulb blown via shot from pellet gun - 188 s, IR chopped - 210 s, new bulb blown via shot from pellet gun (had a momentary flame) - In changing bulbs, people walked in between IR source and OFDs	No Alarms except OFD4 (2-IR) at 31 m, HOA & HVOA at 112 and 110 s (remained in alarm through rest of test) OFD3 (3-IR) at 31 m indicated False 00ult condition at beginning of test for first 2 to 19 seconds
False012	Chopped IR (quartz heater) at 26 m and 150 W incandescent bulb Bulb blown out via shot from pellet gun, Bulb replaced and second bulb blown out (bulb smoked before burning out)	No Alarms
False013	Arc welding at 27 m (in line with 31 m DLS OFDs)	All OFD1 (UV/IR) in UV warning OFD1 at 31 m, HVOA alarmed All OFD3 (3-IR) at 31 m alarmed All OFD6 (3-IR) at 31 m alarmed All other OFDs had no response

Most of the sources used in the fire tests did not produce false alarms. The main exception was arc welding at 27 m from the pad center (3.5 m from the OFDs at 31 m). This source caused both of the 3-IR OFDs (OFD 3 and 6) to alarm at the 31 m location and at all orientations (DLS, HOA, and HVOA). Additionally, the arc welding caused OFD1, a UV/IR detector, to also alarm at the 31 m HVOA location. Welding at a location of 15 m from the pad center (i.e., 16 and 21 m from the two OFD locations) did not produce any alarm conditions. The second exception of a source that produced a false alarm was the chopped IR source at 20 m from the pad center which caused OFD6 (3-IR) to alarm at the 31 m direct line of sight position.

6.8 Effect of Fuel on OFD Performance

The effect of fuel type on OFD performance can be assessed by comparing similar test scenarios (Table 5). Pan fire test scenarios 18 and 21 can be used to compare JP-8 and gasoline,

and the unconfined (scenarios 1 and 19) and confined in the Y direction spill fires (scenarios 14 and 20) can be used for comparisons between JP-8 and JP-5, respectively. The performance of the detectors to each fuel type was assessed by comparing the detector responses (i.e., did the OFD alarm) and the times to alarm between the similar test scenarios.

6.8.1 JP-8 v. Gasoline

The first analysis addresses the use of JP-8 compared to gasoline (Scenario 18 v. 21). The only fires conducted with gasoline were pan fires (Table 5). For the 0.3 x 0.3 m pan fires, Tests 108 (JP-8) and 109 (gasoline) were compared. Both the JP-8 and gasoline fires (~ 100 kW) resulted in the same alarms; OFD6 (3-IR) alarmed at all locations, OFD3 (3-IR) alarmed only at the DLS locations (both 31 and 46 m), and all of the other OFDs did not alarm. Despite the same general response, the alarm times were much shorter for the gasoline fires, ranging from 47 to 167 s shorter with most about 60 s.

Comparison of the 0.6 x 0.6 m pan fires shows similar results between JP-8 and gasoline as did the 0.3 x 0.3 m pan fires. In Figure 26, the heat release rates of the 0.6 x 0.6 m JP-8 pan fires agree very well, reaching a steady-state value of 350 to 450 kW. Figure 28 presents a comparison of the HRR plots from a representative JP-8 fire (Test 13) and the gasoline 0.6 x 0.6 m pan fire (Test 14). The gasoline pan fire grew much faster and reached a higher initial maximum HRR of 550 to 650 kW, which was about 200 kW higher than the JP-8 fires. As the fires burned beyond 180 seconds, the HRRs converged toward the same value of about 460 kW.

Overall, the multispectrum IR detectors, both 2-IR (OFD 4) and 3-IR (OFD3 and 6), responded the same to both the JP-8 and gasoline fires in that they alarmed at all locations for both fires. The UV/IR detectors (OFD1, 2, and 5) responded better to the gasoline pan fires. OFD1 alarmed for all of the gasoline fires but did not alarm at the 46 m off-axis locations for the JP-8 pan fires. OFD5 alarmed at both the 31 and 46 m DLS locations for the gasoline fire but only alarmed at the 31 m DLS location for the JP-8 pan fires. OFD2 did not alarm at any location for either fuel. All of the detectors responded faster to the gasoline fires (12 to 73 seconds faster).

Comparing HRRs at the time of alarm between the JP-8 and gasoline tests shows that there is good agreement in the detectors alarming at the same heat release rate for both fuels. Table 18 presents the HRR data at the time to alarm for the JP-8 and gasoline pan fire tests. The table presents the average HRR values for all three JP-8 fires. The data of the JP-8 pan fires are in excellent agreement with the standard deviations ranging from 0.01 to 0.04 MW (i.e., 10 to 40 kW). For most of the detectors, the HRR values at alarm between the JP-8 and gasoline fire tests vary by less than 100 kW, with the majority less than 50 kW. The largest discrepancies are observed with OFD6 (3-IR), in which the HRRs at alarm are about 150 to 200 kW lower for the JP-8 fires. These differences may not necessarily be differences in the detectable fire size as much as it is uncertainty in test variations in ignition and the calculation method. As can be observed in Figure 28, the gasoline HRR rises extremely fast, which leads to significant differences in HRR values with minor changes in time of alarm. For example, given that the average slope is 33 kW/s, a difference of 3 second response time can lead to a 100 kW difference

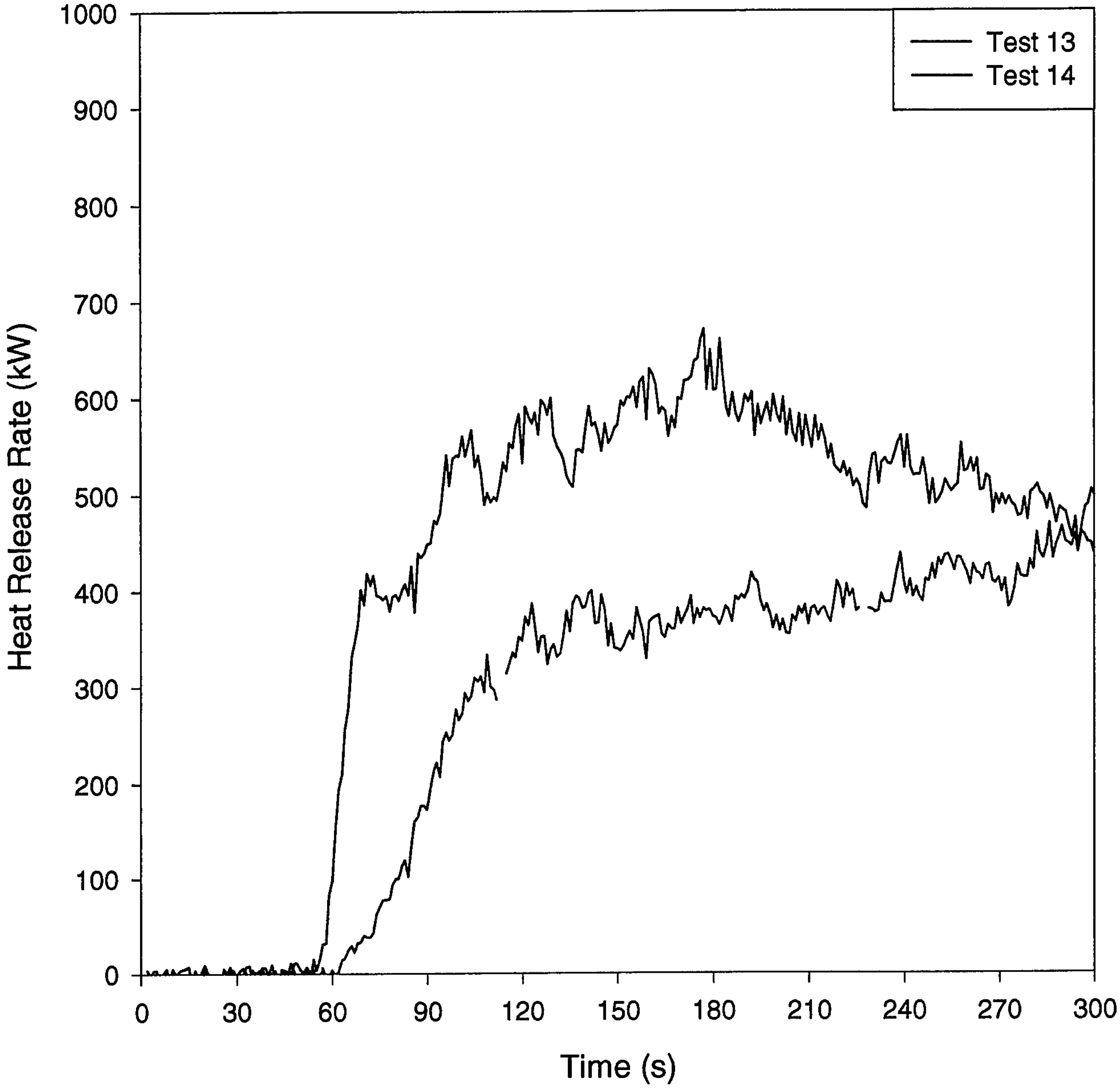


Fig. 28 – Comparison of heat release rates for 0.6 x 0.6 m gasoline (Test 14) and JP-8 (Test 13) pan fires

Table 18. Comparison of the Heat Release Rates (MW) at the Time of Alarm of Each Detector for the JP-8 and Gasoline 0.6 x 0.6 m Pan Fire Tests

Detector	JP-8					Gasoline
	Test 13	Test 103	Test 104	Average	Standard Deviation	Test 14
OFD1A	0.21	0.27	0.25	0.24	0.03	0.25
OFD2A						
OFD3A	0.10	0.09	0.10	0.10	0.01	0.18
OFD4A	0.26	0.19	0.24	0.23	0.04	0.30
OFD5A	0.35	0.30	0.34	0.33	0.03	0.21
OFD6A	0.11	0.12	0.13	0.12	0.01	0.27
OFD1B	0.28	0.29	0.22	0.26	0.04	0.25
OFD2B						
OFD3B	0.11	0.12	0.12	0.12	0.01	0.21
OFD4B	0.25	0.30	0.31	0.29	0.03	0.30
OFD5B						
OFD6B	0.11	0.12	0.10	0.11	0.01	0.35
OFD1C	0.27	0.31	0.21	0.26	0.05	0.27
OFD2C						
OFD3C	0.11	0.12	0.12	0.12	0.01	0.25
OFD4C	0.30	0.29	0.32	0.30	0.02	0.30
OFD5C						
OFD6C	0.11	0.12	0.10	0.11	0.01	0.35
OFD1D	0.35	0.28	0.34	0.32	0.04	0.25
OFD2D						
OFD3D	0.11	0.12	0.12	0.12	0.01	0.18
OFD4D	0.30	0.29	0.30	0.30	0.01	0.30
OFD5D						0.48
OFD6D	0.13	0.13	0.14	0.13	0.01	0.38
OFD1E						0.38
OFD2E						
OFD3E	0.30	0.29	0.27	0.29	0.02	0.25
OFD4E	0.35	0.36	0.37	0.36	0.01	0.40
OFD5E						
OFD6E	0.16	0.13	0.14	0.14	0.02	0.36
OFD1F	0.38					0.40
OFD2F						
OFD3F	0.28	0.26	0.26	0.27	0.01	0.25
OFD4F	0.36	0.35	0.37	0.36	0.01	0.40
OFD5F						
OFD6F	0.13	0.13	0.19	0.15	0.03	0.30

Note: Blanks indicate no alarm

in HRR. Based on the repeatability of fire ignition and growth, alarm times within 10 seconds are considered to be in good agreement. Therefore, the heat release rates of the JP-8 and gasoline fire tests demonstrate that detectors are alarming at the same fire size. Since the gasoline fires grew more rapidly, detector alarm times were faster for the gasoline fires than the JP-8 fires.

The 0.9 m diameter pan fire tests show the same trends and results as did the 0.6 x 0.6 m pan fire tests. The multispectrum IR detectors, both 2-IR (OFD 4) and 3-IR (OFD3 and 6), responded the same to both the JP-8 and gasoline fires in that they alarmed at all locations for both fires (one exception for OFD6, discussed below). The UV/IR detectors (OFD1, 2, and 5) responded better to the gasoline pan fires. OFD1 alarmed for all of the gasoline fires but did not alarm at some of the 46 m off-axis locations for the JP-8 pan fires. OFD5 alarmed at both the 31 and 46 m DLS locations for the gasoline fire but did not alarm at the 46 m DLS location for all the JP-8 pan fires. OFD2 responded the same for both fuels, alarming only at the 31 m DLS locations. All of the detectors responded faster to the gasoline fires.

There were only two notable results of the 0.9 m diameter pan fires compared to the other JP-8 versus gasoline pan fire test comparisons. Both results pertain to OFD6 (3-IR). At the 31 m HVOA location, OFD6 alarmed at 128 seconds after ignition of the gasoline compared to an average of 19 s for the JP-8 fires. At the 46 m HVOA location, OFD 6 did not alarm for the gasoline fire, but alarmed at 24 and 25 seconds for the JP-8 fires. Unfortunately only one gasoline 0.9 m test was conducted. Based on the limited data, there is no explanation for the reduced performance of these two detectors with the gasoline fires, which is contrary to all other results.

In summary, gasoline pan fires grew more rapidly and to higher heat release rates than the JP-8 pan fires. This faster fire growth lead to shorter detector alarm times with the gasoline fires. The test data indicates that the detectors alarmed at equivalent fire sizes for both the JP-8 and gasoline fires. The ability of the multi-spectrum IR (both 2-IR and 3-IR) OFDs to detect the pan fires evaluated was not dependent on the fuel type. However, the UV/IR detectors were able to detect and indicate alarms at more locations with gasoline fires than with JP-8 fires.

6.8.2 JP-8 v. JP-5

The effect of fuel type between JP-8 and JP-5 fires on detector performance was analyzed for both unconfined spill fires and confined spill fires. The analysis of the unconfined spill fires consisted of comparing the 0.17 Lpm and 1.7 Lpm test results of Scenarios 1 and 19. The tests of scenarios 14 and 20 were used for establishing comparisons between JP-8 and JP-5 spill fires confined in the Y direction.

In general, there was little difference in the performance of the OFDs between the JP-8 and JP-5 spill fires. The fire growth rates were very similar for the two fuels. Consequently since these fuels are also similar in chemical composition, the detector responses (i.e., which OFDs alarmed) were the same, as well as the time to alarms. The exceptions to these general results were: 1) OFD2 (UV/IR) alarmed for only one of four tests at the 31 m DLS location during the JP-5 fires, but alarmed for three of four tests at the 31 m DLS location for the JP-8

fires, and 2) the alarm times for the 0.17 Lpm unconfined spill fires (~ 100 kW) were shorter for the JP-5 fires (~10 to 40 seconds based on the averages of all tests).

The alarm responses (i.e., which OFDs alarmed) were the same for both the JP-8 and JP-5, 0.17 Lpm unconfined spill fires. However, the JP-5 fires grew faster, reaching steady-state values sooner than the JP-8 fires. Figure 29 shows a comparison of the heat release rate data for the JP-8 and JP-5, 0.17 Lpm unconfined spill fires. As noted in Section 6.3.1 and seen in Figure 29, the repeatability of the 0.17 Lpm JP-8 test fires was not very good due to variations in the concrete slab temperature. The HRR data for the JP-5 fires is in very good agreement (the concrete slab temperatures were within 2°C for all three tests). Figure 29 shows that the JP-5 fires grew more rapidly than all of the JP-8 fires. The reason for this difference is not clear, particularly since it was expected that the JP-8 fires would grow faster since JP-8 has a lower flash point. Table 19 presents the concrete slab temperatures and the measured flash point temperatures for the JP-8 and JP-5, 0.17 Lpm unconfined spill fires. The difference between the concrete temperatures and the flash points are the same for both fuels. This data does not offer an explanation as to why the JP-5 fires grew faster than the JP-8 fires.

Table 19. Comparison of the Concrete Slab Temperatures and the Measured Flash Point Temperatures for the JP-8 and JP-5, 0.17 Lpm Unconfined Spill Fire

Fuel	In-slab Temperature (°C)	Surface Temperature (°C)	Measured Flash Point (°C)
JP-5	53 - 55	40 - 45	62
JP-8	43	31 - 35	52

There were no significant differences between the OFD results for the JP-8 and JP-5 spill fires confined in the Y direction. The same detectors (and locations) alarmed and the alarm times were approximately the same. The heat release rate curves agreed well between the JP-8 and JP-5 fires.

6.8.3 Summary

The use of JP-8 compared to gasoline pan fires provided a greater challenge to the optical fire detectors, i.e., resulting in longer response times for all detectors and smaller fields of view for UV/IR detectors. There was not a significant difference in the OFD results between the JP-8 and JP-5 spill fires. Considering that the JP fuels are representative of the fuels used in the Navy and that the corresponding fires provide a better test of the performance limits of OFDs, JP fuels should be used in performance specification testing of OFDs for Navy hangar applications. Based on the tests conducted in this program, there is not a clear recommendation on whether to use JP-8 or JP-5. The use of JP-5 may provide a slightly greater challenge to some detectors with respect to the ability to detect a fire.

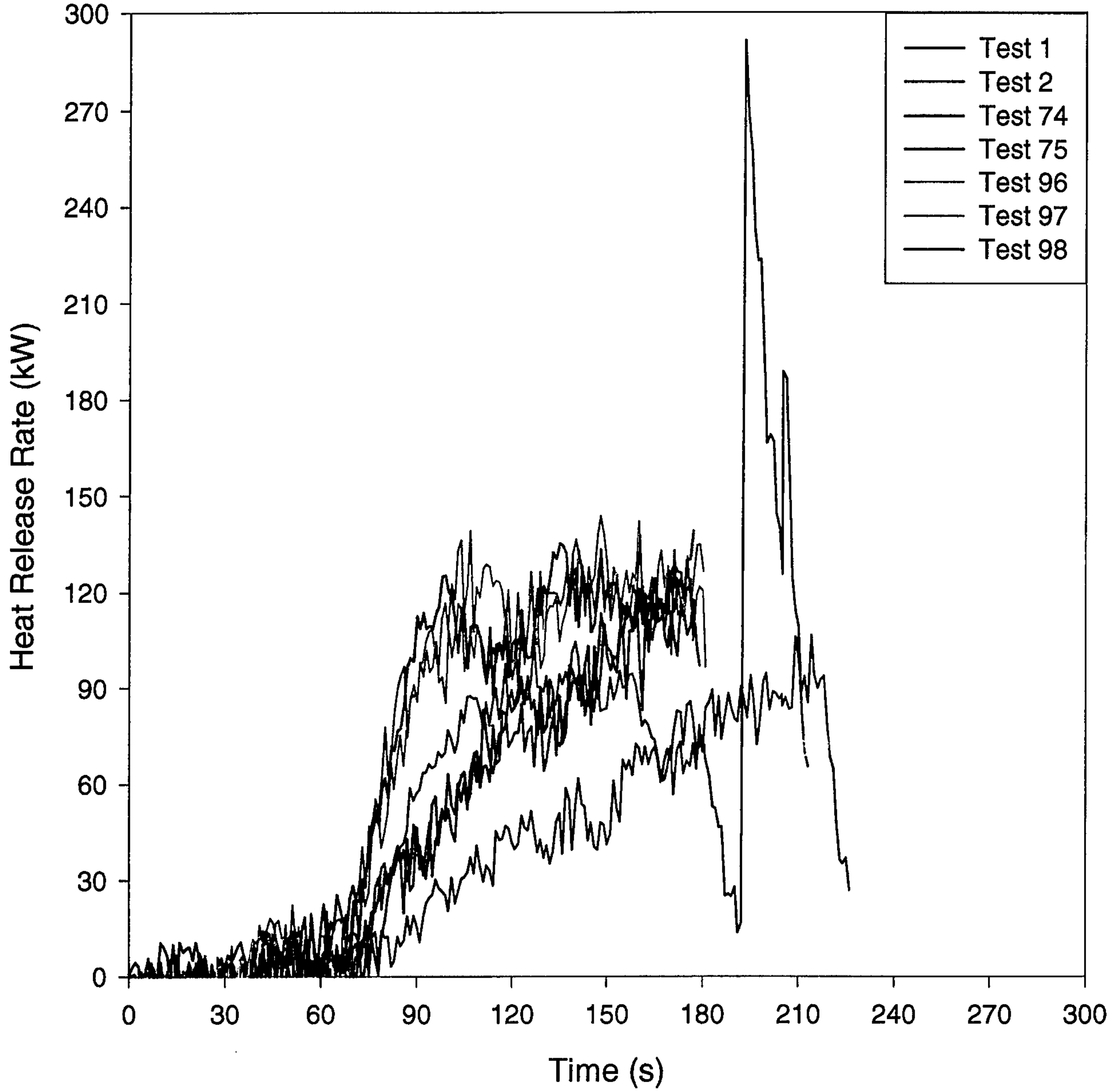


Fig. 29 – Comparison of heat release rates for 0.17 Lpm unconfined spill fires using JP-8 (Tests 1, 2, 74, 75) and JP-5 (Tests 96, 97, 98)

6.9 Pan v. Spill Fire Scenario

In order to make credible comparisons between pan fire tests and spill fire tests, it is necessary to compare the tests on an equivalent basis. Attempts were made to identify pan fires and spill fires which had the same relative heat release rates. Table 20 summarizes the size of the various JP-8 pan and unconfined spill fires. It is difficult to make direct comparisons for the larger two pan sizes which have heat release rates that fall between the different spill fire scenarios. Nevertheless, comparisons between pan fires and unconfined fires with similar HRR are still instructive.

Table 20. Summary of JP-8 Pan and Unconfined Spill Fire Sizes

Pan	Steady-state HRR (MW)	Unconfined Spill (Scenario 1)	Peak HRR (MW)
0.3 x 0.3 m	~ 0.1	0.17 Lpm	~ 0.08 - 0.11
0.6 x 0.6 m	~ 0.35 - 0.4	0.42 Lpm 0.85 Lpm	~ 0.25 ~ 0.45 - 0.55
0.9 m dia.	~ 0.6 - 0.75	1.7 Lpm	~ 0.85 - 0.95

Comparisons were made between the 0.3 x 0.3 m pan fire Test 106 and the 0.17 Lpm JP-8 unconfined spill fire Tests 2, 74, and 75, which had similar fire growth curves (Figure 30). In Figure 30, the heat release curves are in reasonable agreement. Comparison of the detector responses for these tests showed that there was very little difference in which detectors alarmed for each type of fire. All of the detector models except OFD1 responded the same at all locations and positions. OFD1 did not respond to the pan fire but did respond to the spill fire at 31 m DLS and for most of the off-axis 31 m positions. There was no significant difference in the alarm times of the detectors between each scenario.

A second comparison was made between the JP-8, 0.6 x 0.6 m pan fire Tests 13, 103, and 104 and both the JP-8, 0.42 Lpm and 0.85 Lpm unconfined spill fire tests. Table 20 brackets the HRR of the two sets of unconfined spill fire tests around the HRRs of the pan fires. Comparison of the pan fires with the 0.42 Lpm tests shows that the pan fire yields more alarms than the spill fires, which were smaller and had a slower growth rate (i.e., 0.004 MW/s vs. 0.009 MW/s for the pan fires). The 0.85 Lpm spill fires had slightly larger HRR than the pan fires. In comparing these tests, OFD models 6, 3, 5, and 2 had the same alarm responses for both the pan and unconfined spill fires. OFD1 (UV/IR) had a few less alarms with the 46 m off-axis detectors when exposed to the pan fire, while OFD4 (2-IR) had a few less alarms with the 46 m off-axis detectors when exposed to the spill fire. OFDs 3 and 6 (both 3-IR) had approximately the same alarm times for both the pan and spill tests. Alarm times for OFD1 were 10 to 90 seconds slower for the pan fires and OFD4 had alarm times that were about 5 to 10 seconds slower for the pan fires (differences below 10 seconds are not considered significant given the uncertainties in test repeatability and timing). Summarizing:

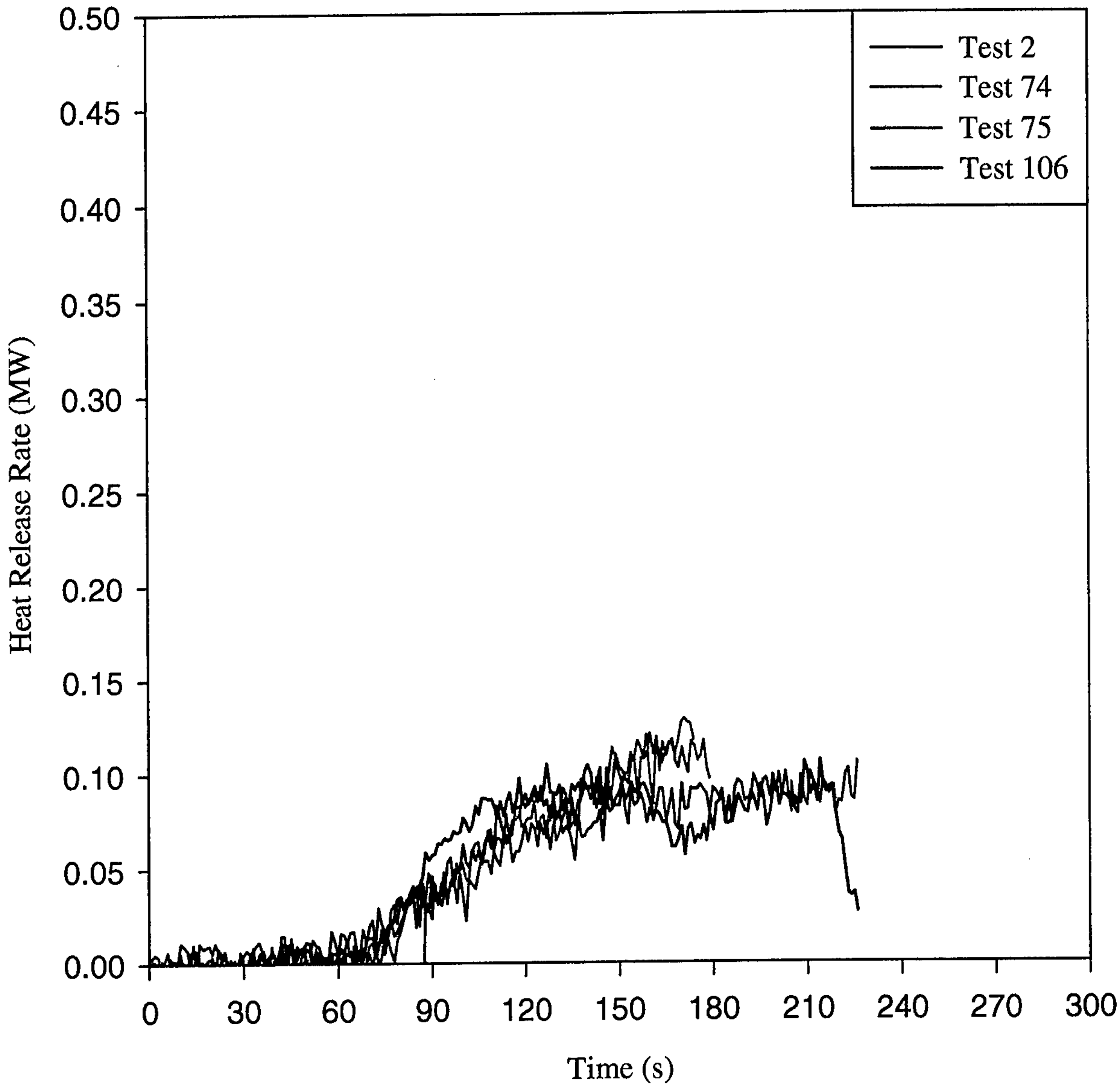


Fig. 30 – Comparison of heat release rates for JP-8 0.17 Lpm unconfined spill fires (Tests 2, 74 and 75) and a JP-8 0.3 x 0.3 m pan fire (Test 106)

1) 0.3 x 0.3 m v. 0.17 Lpm
   a) All OFDs same response except OFD1 (UV/IR), which had no alarms for the pan fire but some for spill fires.
   b) Alarm times were approximately the same.
2) 0.6 x 0.6 m v. 0.42 Lpm
   a) More alarms for pan fires which are larger and grow faster.
   b) However, direct comparisons are not possible due to variations in heat release rates.
3) 0.6 x 0.6 m v. 0.85 Lpm
   a) OFD2, 3, 5 and 6 had same alarm responses, OFD3 and 6 (3-IR) had same alarm times.
   b) OFD1 had a few less alarms with pan fires, alarm times slower (10 - 90 s) with pan fires.
   c) OFD4 had a few less alarms with spill fires, alarm times slower (5 - 10 s) with pan fires.

Based on the data available from this test program and the analysis discussed above, it is unclear whether the unconfined spill fires provide a unique challenge to the OFDs compared to pan fires.

6.10 Unconfined v. Fixed Quantity Spill Fire Scenario

Comparison of OFD performance between unconfined and fixed quantity spill fires was performed by analyzing the results of test with fires of comparable size. As indicated in the previous sections, detector performance is very dependent on fire size. Table 21 compares the peak heat release rates of the unconfined and fixed quantity spill fires. Based on the data of Table 21, the 1 L fixed quantity spill fire (Test 9) was compared to the 0.85 Lpm unconfined spill fire tests (5, 6, 78, and 79). Although there were similar responses overall, there were fewer detector alarms with the fixed quantity spill fires. OFD1 (UV/IR) and OFD3 (3-IR) did not alarm at some of the 46 m off-axis locations, and OFD4 (2-IR) did not alarm at any of the 46 m locations for the fixed quantity spill fire. There was no significant difference in alarm times (i.e., < 10 s) for the two fire scenarios.

Table 21. Summary of JP-8 Fixed Quantity and Unconfined Spill Fire Sizes

Fixed Quantity (Scenario 12)	Peak HRR (MW)	Unconfined Spill (Scenario 1)	Peak HRR (MW)
1 L	~ 0.5	0.17 Lpm	~ 0.08 - 0.11
2 L	~ 1.1 Test 99 ~ 0.28 - 0.33 Test 10,11	0.42 Lpm 0.85 Lpm	~ 0.25 ~ 0.45 - 0.55
3 L	~ 1.6 - 2.0 ~ 0.9 Test 12	1.7 Lpm	~ 0.85 - 0.95

A second comparison was made between Tests 10 and 11 (2 L fixed quantity) and Tests 3, 4, 76, and 77 (0.42 Lpm unconfined spill fires). The detector responses were very similar for most detectors and locations. OFD4 (2-IR) had fewer alarms with the unconfined spill fires at multiple locations. There were some differences in the number of alarms at the 46 m off-axis locations for OFD3 (3-IR) and OFD1 (UV/IR), however, no consistent trend was apparent with respect to the fire scenario and detector performance.

A third comparison was made between fixed quantity Tests 99 (2 L) and 12 (3 L) and unconfined spill fire Tests 7, 8, 84, and 85 (1.7 Lpm). Figure 31 shows a comparison of the heat release rate data for these tests. Although the final peak HRR is approximately the same for all of the fires, there are significant differences in the growth stage of the fires. As noted in Section 6.3.3, the spill fire in Test 12 was apparently affected by surface features of the concrete which yielded the somewhat disjointed growth period as shown in Figure 31. The other fixed quantity spill, Test 99, grew rapidly at a faster rate than the unconfined spill fires. The detector responses were very similar for most detectors and locations. The only notable difference was that OFD2 (UV/IR) did not alarm at any location for the fixed quantity spill fires but did alarm for 3 of 4 tests at the 31 m DLS location. There were a few differences at the 46 m off-axis locations for OFD3 (3-IR) and OFD4 (2-IR), but these differences existed between the fixed quantity tests (99 and 12) as well as between the fixed quantity tests and the unconfined tests. The tests do indicate that the very fast growing fire (Test 99) was the most challenging fire. It was with this fire that OFD3 and 4 did not alarm at some of the 46 m locations and OFD2 and 5 (both UV/IR) did not alarm at the 31 m DLS locations as they did with the unconfined spill fires. Overall, the alarm times were shorter with the fixed quantity spill fire (Test 99) compared to the unconfined spill fires. The HRR values at the time to alarm were greater for the unconfined spill fire tests (~ 50 to 650 kW). The potential increased challenge in detection capability for some models with the fixed quantity spill fire is believed to be primarily a function of the rapid growth rate of the fire.

The above comparisons demonstrate that there is not a substantial difference between the fixed quantity and unconfined spill fire scenarios with respect to OFD performance. As discussed previously, conducting repeatable fixed quantity spill fires is more difficult than conducting the unconfined spill fires.

6.11 Confined v. Unconfined Spill Fire Scenario

The confined spill fire scenarios represent cases when cabling or other obstacles in a hangar may channel fuel in a narrow spill geometry. Prior to testing it was not clear to what degree the depth of the flame affected OFD performance. Comparing the results of the X-direction confined spill fire tests to those of similar HRR unconfined spills provides such a measure. The growth curves and fire sizes were very different for equivalent flow rates between the confined and unconfined spill scenarios. For instance, a 0.85 Lpm setting yielded a 500 kW unconfined fire and less than a 250 kW confined spill fire. Despite the differences, limited comparisons can be made between confined and unconfined fires of different flow rates that had equivalent HRRs.

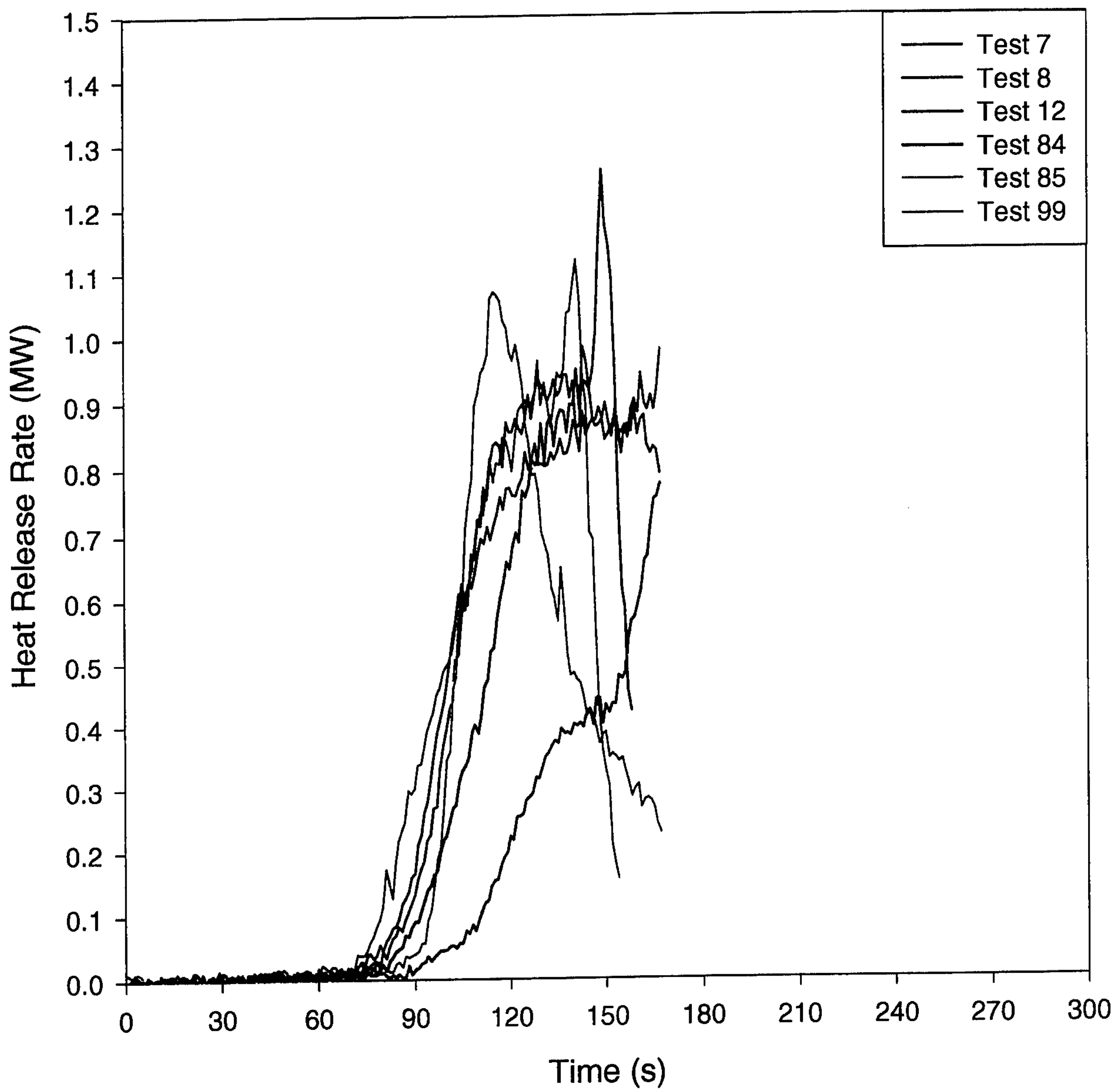


Fig. 31 – Comparison of heat release rates for 1.7 Lpm unconfined spill fires (Tests 7, 8, 84, 85) and fixed quantity spill fires (Tests 12 and 99)

A 0.42 Lpm confined spill fire (Test 20) was compared to the 0.17 Lpm unconfined spill fire tests (2, 74, and 75). Figure 32 shows a plot of the heat release rates of these fires. All of the detector responses were the same for both fire scenarios except for OFD1 (UV/IR). With the X-direction confined test, OFD1 did not alarm at any location; with the unconfined spill fires, OFD1 alarmed at 31 m DLS for all tests and at 31 m off-axis locations for half the tests. OFD2, 4 and 5 did not alarm for either scenario. Therefore, this comparison shows that for the three band multispectrum IR detectors (OFD3 and 6), the ability of a detector to respond to a fire is not affected by flame depth for these small fires. However, the alarm times were shorter for the confined spill fires, by 20 to 40 s for OFD3 and by 10 to 20 s for OFD6. The alarm times indicate that the unconfined spill scenario provides a better means for evaluating 3-IR OFD performance. One UV/IR detector (OFD1) had diminished detection capabilities with the confined test. Since the other detectors did not respond to either scenario, it is unclear whether the flame geometry will effect the detection capability, particularly at larger fire sizes. Evaluation of other tests, such as Tests 24 and 25 (0.42 Lpm confined) versus 3, 4, 76 and 77 (0.42 Lpm unconfined, ~ 250 kW), yielded similar conclusions.

Conducting confined spill fires with larger HRRs (>300 kW) would require trenches that are either longer or wider. Widening the trench reduces the geometric aspect ratio which is the parameter being evaluated, and lengthening the trench to significant size is not practical. Based on these considerations, the use of a confined spill fire in the X-direction is not recommended as a performance specification test.

6.12 Confined X v. Y Direction Spill Fire Scenario

Comparison of OFD results from the spill fires confined in the X direction (Scenario 13) and in the Y direction (Scenario 14) show no significant difference in detector performance (Appendix C). Both the number and locations of alarms as well as the times to alarm were in good agreement, considering the variations in the heat release rates of the different test fires. These results indicate, particularly for small fires, that flame geometry is not a primary factor in OFD performance.

6.13 Spill Fire Growth

An engineering evaluation of spill fires usually begins with an estimation of the fire size based on either the final spill area or on a continuous spill rate [10,15]. Either calculation is dependent on a fuel burning rate, which can be expressed as mass loss per unit time per area (kg/m^{2}s). Typically, the mass burning rate is obtained from data compiled by Babrauskas [10]. The following equation is used to calculate the burning rate at a given pool diameter, D, knowing the burning rate per unit area for an infinite-diameter pool, $\dot{m}''_{\infty}$:

$$\dot{m}'' = \dot{m}''_{\infty}(1-e^{-k\beta D}) \tag{1}$$

The term $k\beta$ is the product of the extinction-absorption coefficient of the flame (k) and the mean-beam-length correction (β). Babrauskas presents data that indicates that the mass burning rate

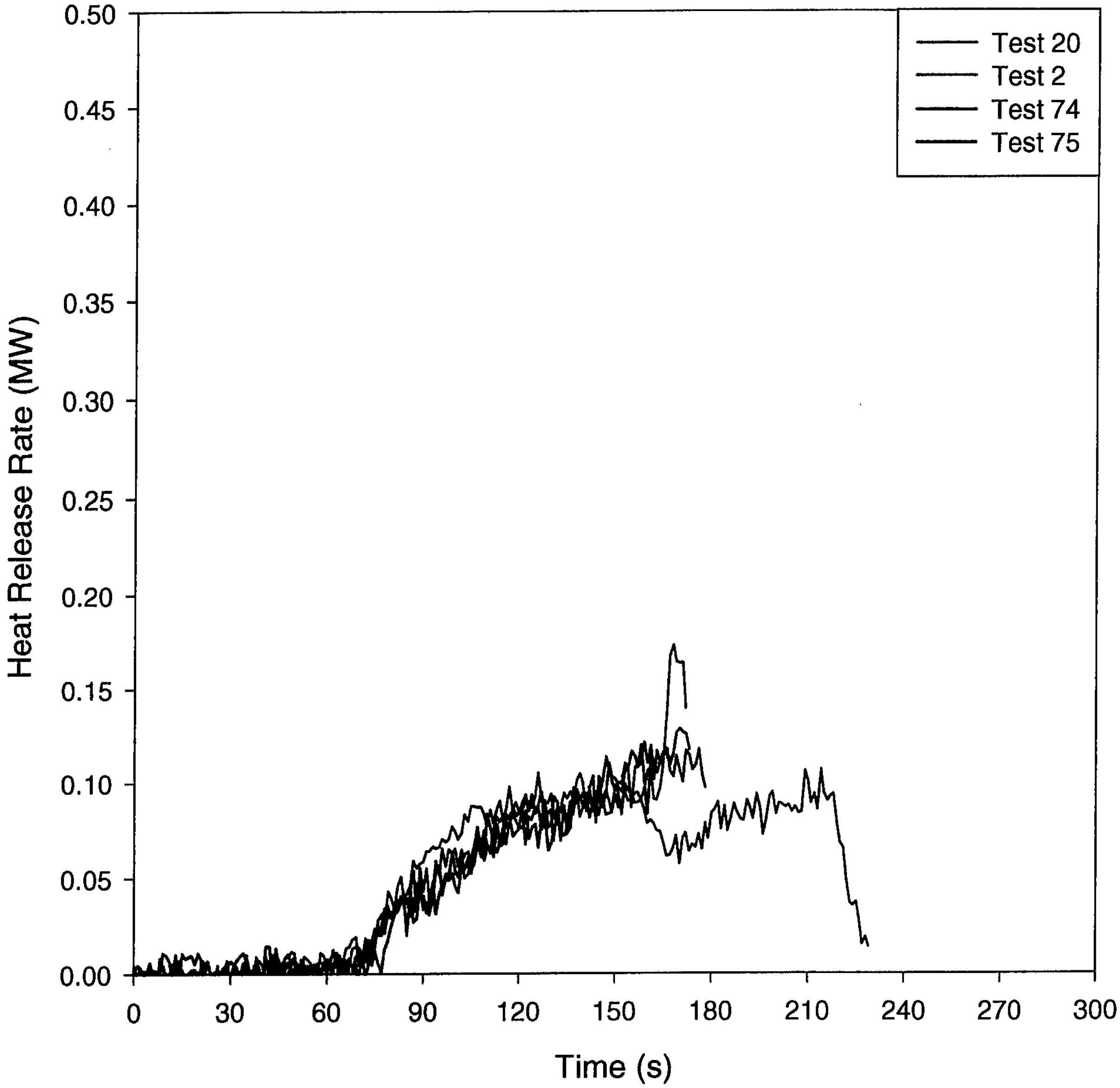


Fig. 32 – Comparison of heat release rates for a 0.42 Lpm JP-8 spill fire confined in the x-direction (Test 20) and 0.17 Lpm JP-8 unconfined spill fires (Tests 2, 74, 75)

per area approaches $\dot{m}''_\infty$ at pool diameters of 1 to 2 m. For JP-4 and JP-5 fuels, the reported values of $\dot{m}''_\infty$ are 0.051 and 0.054 kg/m^{2}s, respectively.

Average values of $\dot{m}''$ were calculated for the multiple unconfined JP-8 spill fire tests conducted in this study. The average values represent the steady-state burning behavior for the repeat tests at three of the four fuel flow rate settings (0.42, 0.85, and 1.7 Lpm). Due to greater uncertainties with the heat release rates of the 0.17 Lpm tests, data for this scenario is not presented. The mass burning rates were calculated using the measured heat release rate ($\dot{Q}$), the measured pool area (A) from video records, and the heat of combustion (Δh_c) reported in Table 1:

$$\dot{m}'' = \frac{\dot{Q}}{\Delta h_c A} = \left(\frac{kg}{m^2 s}\right) \tag{2}$$

Figure 33 shows a plot of the calculated mass burning rates as a function of the spill fire diameter. Also plotted on Figure 33 are the curves derived from Babrauskas' correlation (Equation 2) and the available published data [10]. The mass burning rates per unit area for the spill fires are approximately 20 to 25 percent of the published data for pool fires. Because of the much smaller burning rates for these spill fires, it was also observed that the pool diameters for the spill fires were approximately twice as large as would typically be calculated for pool fires of the same heat release rate. The observed differences between the spill fires of this study and the published data is primarily attributed to the fact that the published data is derived from tests of confined pool fires, which also have larger fuel depths. Though a complete analysis has not been performed on the flame heights, initial observations of the data indicate that the flame height correlations (e.g., Heskestad's correlation [16,17]) typically used in pool fire dynamics calculations are also not applicable to the spill fires given the differences in pool area.

7.0 OPTICAL STRESS IMMUNITY TESTS

Appendix E contains a report detailing the results of the optical stress immunity tests [18]. These tests were conducted to determine the susceptibility of the detectors to various optical stresses representative of potential false alarm sources. A detection system prone to false alarms becomes impractical due to the cost of unnecessary suppression system activation and consequently, may not even be used (i.e., the detection system is deactivated).

The tests conducted used the basic test procedure developed by NRC along with additional optical stress tests. The tests were conducted by NRC. The rank order of performance of the OFDs to the optical stresses is in good agreement with the fire test results. The OFD models OFD3 and 6 (3-IR) responded to a very limited number of nuisance source test conditions. OFD1 (UV/IR) and OFD4 (2-IR) responded to a range of test conditions, and OFD2 and 5 (UV/IR) responded to a wider range of conditions. The models that performed best in the fire tests, also performed well with respect to nuisance alarm immunity.

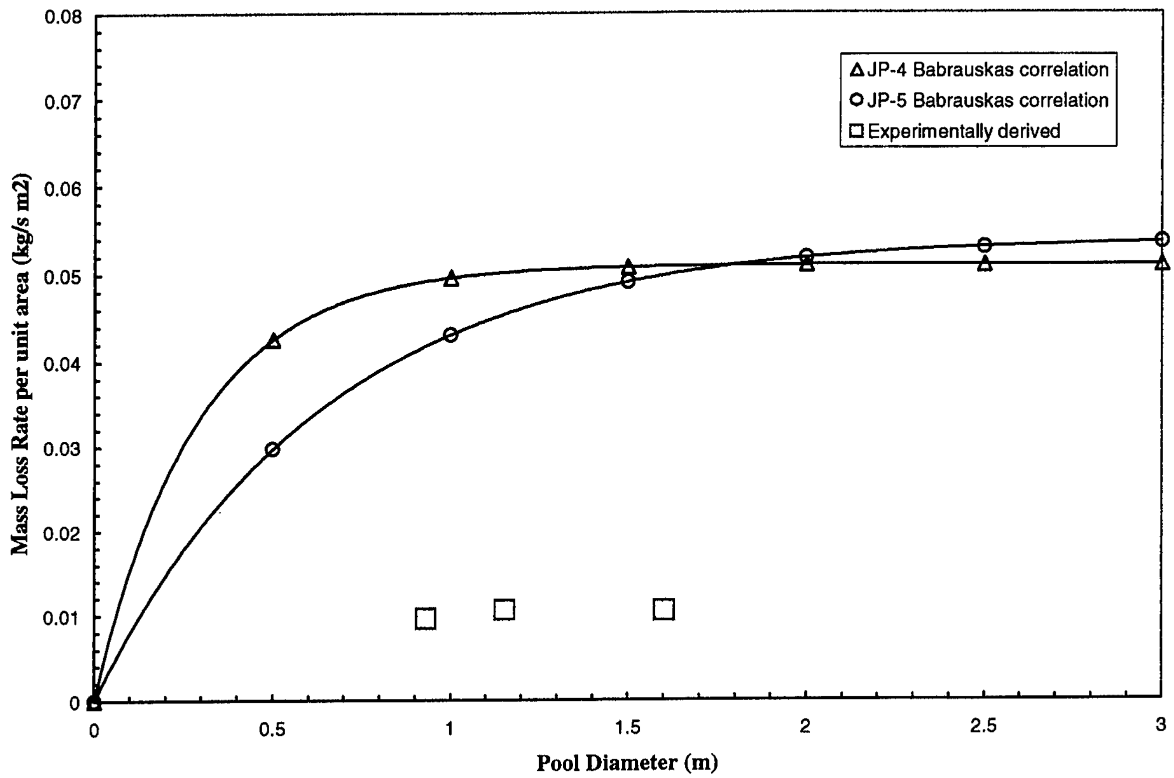


Fig. 33 – Average steady-state mass burning rate per unit area plotted versus pool diameter for JP-8 spill fires

8.0 COLLATERAL DAMAGE THREAT ASSESSMENT

The experimental program provides rank ordering of detector performance for fire detection and immunity to false alarms. The absolute detection times need to be evaluated in terms of acceptable limits in order to establish performance criteria. An approach was used that considered response times characteristics which would limit potential collateral damage of aircraft to an adjacent fire. Specifically, a methodology for determining the extent of collateral damage was developed. A transient radiation model of heat transfer from a spill fire to an aircraft component was utilized.

Measurements of incident heat flux to objects outside of the fire were obtained in the OFD fire testing (Section 5.6.3). These measurements were to serve as validation data for evaluating the heat transfer model. During the development of the model, it became apparent that, given the state of the art, developing an accurate heat transfer model between transient spill fires and relatively close targets was not possible. A point source model was selected as an appropriate technique for providing a conservative hazard assessment. This assessment considered critical aircraft component failure temperatures, along with the time to discharge AFFF agent and control a fire. Finally, capabilities of detector technologies were considered in establishing performance criteria.

8.1 Development of Model

Figure 34 shows a schematic of the heat transfer model. The governing differential equation is

$$c\rho\delta\frac{dT_s}{dt} = \dot{q}''_{inc} - \dot{q}''_{rad} - \dot{q}''_{conv} \tag{3}$$

where C is the heat capacity of the target,
ρ is the density of the target,
ζ is the thickness of the target material,
T_s is the surface temperature of the target,
t is the time,
$\dot{q}_{inc}$ is the incident heat flux on the target,
$\dot{q}_{rad}$ is the radiated heat flux from the target to its surroundings, and
$\dot{q}_{conv}$ is the convected heat flux at the target surface.

This model assumes that the back surface of the target material is insulated (i.e., no heat loss) and that the material can be treated as lumped mass (i.e., isothermal, there is no temperature gradient across the material). These assumptions are reasonable for aluminum skin targets. The lumped mass assumption may not be accurate for composite materials.

Equation 3 can be numerically integrated to yield a solution for the surface temperature as a function of time. In order to do so, the material properties must be specified and the heat transfer terms must be defined, either as constants or functions of other known or calculated parameters. Since the goal was to develop a transient model, the heat flux terms are not

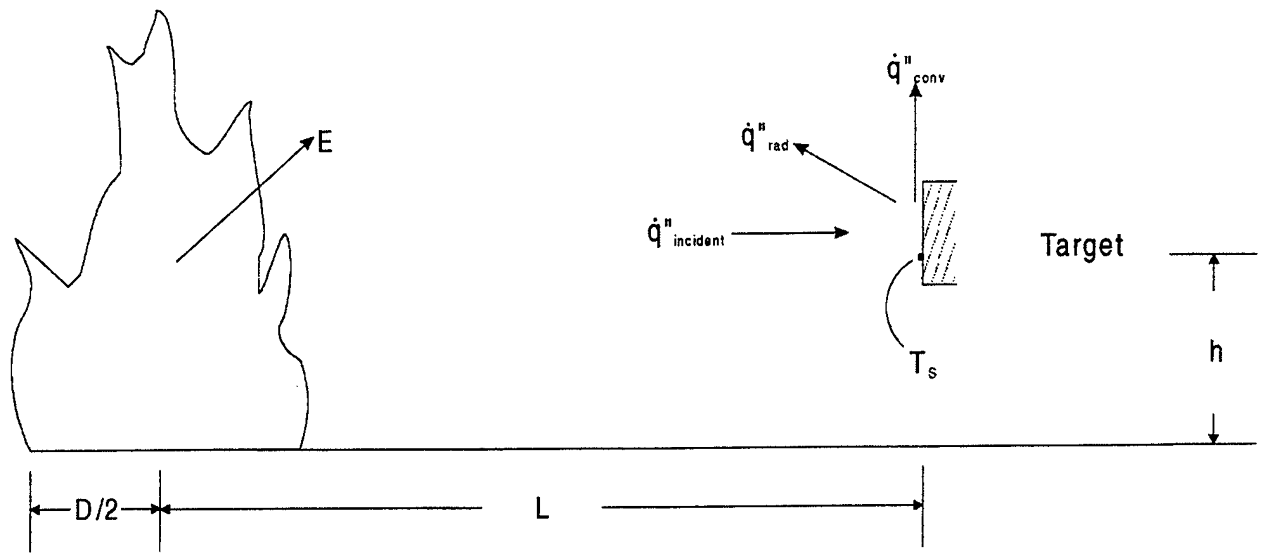


Fig. 34 – Schematic of heat transfer model

constants. As the spill fire grows from ignition toward a steady-state or peak value, the heat fluxes as well as the surface temperature will vary.

The primary difficulty in performing the heat transfer analysis is calculating the incident heat flux to the target. Several methods are briefly discussed below:

Use the Emissive Power, E, of the Fire:

$$\dot{q}'' = F_{1\text{-}2}E \tag{4}$$

where $F_{1\text{-}2}$ is the view factor from the fire to the target (i.e., the fraction of the total energy emitted by the fire incident on the target). The view factor is a function of geometry, which includes the distance between the fire and the target and the heights of each. Several correlations of the emissive power from pool fires have been developed [15,19]. However, these correlations are not applicable for small pool fires (< 1 m diameter); in fact at a diameter of 1 m, the two correlations yield emissive powers that vary by more than a factor of 2 (~ 126 and 57 kW/m^2). This uncertainty at small diameters is problematic since the spill fires transition through this regime. Secondly, the correlations have been developed from confined pool fire data which has been shown to be significantly different than spill fire data with respect to fire size to pool diameter relationships (see Section 6.13). Therefore, the applicability of these correlations is questionable. There are no established correlations for small pool fires (i.e., < 2 m diameter) that can be effectively applied to the spill fires, nor are there any known correlations for spill fires in general.

Use of a Point Source Model:

This model assumes that the fire is represented as a small source of energy radiating to the target. The amount of energy radiated is specified as a fraction of the total energy released from combustion. Using the point source model, it has been shown that the incident flux to a target, $\dot{q}''$, is proportional to the inverse square of the distance between the source and the target, R [15]:

$$\dot{q}'' = \frac{\dot{Q}_R \cos\theta}{4\pi R^2} \tag{5}$$

where $\dot{Q}_R$ is the radiation energy output from the fire and is expressed as

$$\dot{Q}_R = X_R \dot{Q} \tag{6}$$

where X_R is the radiative fraction of the flame. The total heat release rate of the fire, $\dot{Q}$, can be specified from known information or calculated using the mass burning rate, m, and the heat of combustion, Δh_c:

$$\dot{Q} = \dot{m}\Delta h_c \tag{7}$$

In order to use the point source model an assumption of the radiative fraction of the spill fires must be made. Figure 35 shows a plot of radiative fraction as a function of pool diameter developed from confined pool fire tests [20]. For pool fires less than 2 m, there is a large variance in the data. Radiative fractions range from 0.08 to 0.3. In developing a transient model of fires that will grow from zero to several meters in diameter, the uncertainty in the radiative fraction data leads to significant problems in maintaining a reasonable degree of accuracy in the heat transfer model. The additional concern with the use of a correlation as presented in Figure 35 is that the data is derived from confined pool fire tests. It is expected that the differences in the burning characteristics of spill fires compared to confined pool fires will lead to a different correlation.

One problem with applying the point source model, is that at distances close to the fire, the model is not valid. Analytical modeling would suggest that the point source model should be valid within 15 percent for ratios of R (distance between fire and target) over pool radius (r) of 3 or greater (within 25 percent for ratios greater than 2) [21]. However, using the heat flux and heat release rate data from the OFD spill fire tests indicates that the point source model is not always applicable at these close distances. For example, even with a well characterized pan fire (Test 13, HRR of 350 kW) with a R/r ratio of 5.8, the radiative fraction calculated using Equations 5 - 7 to a heat flux meter 2 m away is 0.8. This value is two times greater than the highest radiative fractions (0.4) typically reported in the literature. Calculating the radiative fraction for the same fire but at the location of the 3 m heat flux meter (R/r of 8.7), yields a value of 0.42. Given that the fire conditions are the same, the radiative fractions at the two locations should be equivalent. These results demonstrate that the point source model is not valid at the closer distance. Without heat flux data further from the fire source, it is not possible to determine whether a radiative fraction of 0.4 is correct or whether the ratio of R/r is still too small for valid application of the model. Similar results were obtained for a larger, 0.9 m diameter pan fire (Test 15, HRR of 700 kW). The calculated radiative fractions at 2 m (R/r = 2.5) and 3 m (R/r = 6.7) away were 0.8 and 0.45, respectively.

Although the technical challenges prevent accurate transient modeling of the heat transfer from a spill fire, it is possible to evaluate bounding conditions. One example is presented for a transient model that employs the use of the Shokri and Beyler emissive power correlation and the assumption that the fire heat release rate, and thus the emissive power, is constant and equal to the steady-state value (58 kW/m^2). In this example, the mass burning rate per area calculated for the spill fires was used (0.011 kg/m^{2}s). The model was then used to calculate the surface temperature as a function of time for a 0.0016 m thick 2024-T3 aluminum target positioned 1.2 m high, 3.3 m away from a 900 kW JP-8 pool fire. As expected, the model yielded very conservative results. The calculated times at which the surface temperature reached values of

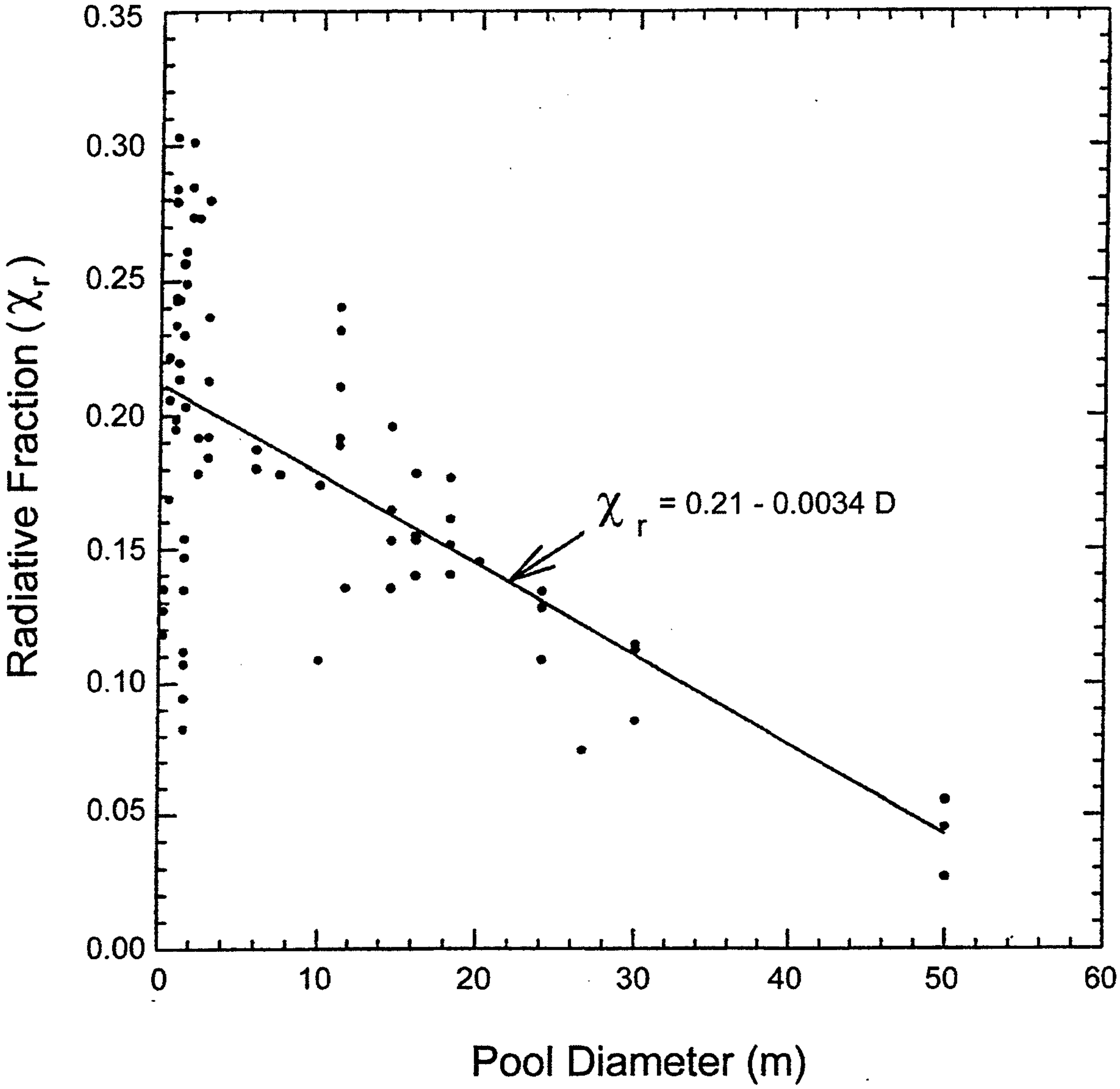


Fig. 35 – Radiative Fraction (χ_r) as a function of pool diameter [20]

150 and 200°C are 155 and 269 s, respectively. The actual measured surface temperature at 155 s was 34°C for Test 7. The model significantly over predicted the surface temperature, 150°C versus 34°C.

The point source model was used to evaluate the same scenario as discussed above for the transient model that employs the Shokri and Beyler emissive power correlation. The transient point source model calculated the surface temperature as a function of time of a 0.0016 m thick 2024-T3 aluminum target positioned 1.2 m high, 3.3 m away from a 900 kW JP-8 pool fire. The radiative fraction was assumed to be 0.4. The point source model also yields conservative results, but for this example, the agreement is closer than obtained with the model using emissive power. The surface temperature was calculated to be 73°C at a time of 155 s, compared to 150°C for the emissive power model and a measured surface temperature of 34°C for Test 7. An analysis of the point source model for larger fuel spill fires showed that the technique compared very favorably to experimental data [3]. Based on the results of this study as well as the previous analysis, it was decided to use the point source model as a conservative tool for defining the limiting boundary of collateral damage.

8.2 Hazard Analysis

The first step in the hazard analysis was to establish critical temperatures for aircraft component failure. A number of sources and techniques were available. Using data in the literature, it is known that the aluminum skin of an aircraft can begin to structurally fail at temperatures on the order of 100-200°C (Figures 36 and 37). Further evidence of critical temperatures was obtained from the Naval Air Systems Command [23,24]. For the E-2C aircraft, the general consensus of the engineers, including consultation with Grumman engineers, was that exposure to 93°C (200°F) for longer than 1 minute will cause parts to deteriorate (value is a best estimate from people with field experience; it is not documented with specific tests). For the V-22 aircraft, the V-22 SD-572-1 specification states that "acrylic plastics (canopy) shall not be exposed to temperatures above 250°F" (121°C). Given the above data for typical aluminum and components used in aircraft and the data from Air Systems Command, it is reasonable, and conservative, to use a temperature range of 100-150°C as the critical temperature in the collateral damage modeling.

Table 22 shows dimensions for various Naval aircraft. A target height of 1.2 m (4 ft) is representative of potential damage locations on the aircraft. This height was used in the modeling effort. It also corresponds to the location of the heat flux meters and targets used in the experimental fire test program.

The modeling also assumed a target sample thickness of 81 mm (0.032 in.). This represents a thin material, and thus, a potentially worst case scenario for achieving the critical temperature. Thicker materials will take longer to heat to the critical temperature. Obtaining actual aluminum aircraft skin properties was very difficult. At best, an estimate of the V-22 aircraft skin thickness was provided to be approximately 2.5 mm (0.1 in). A print out of the model inputs and the calculations for the point source model are presented in Appendix F.

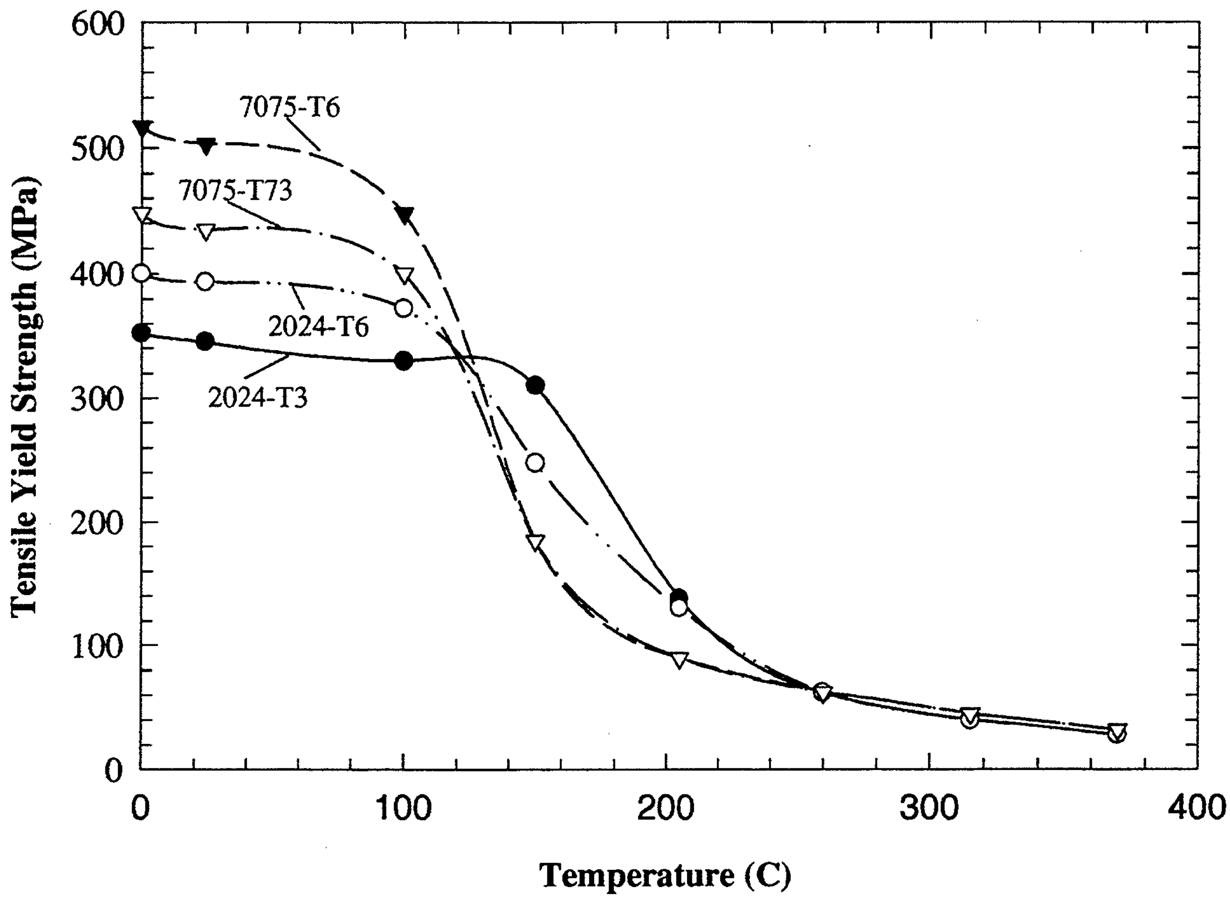


Fig. 36 – Tensile yield strength for aluminum alloys. Data from reference [22]

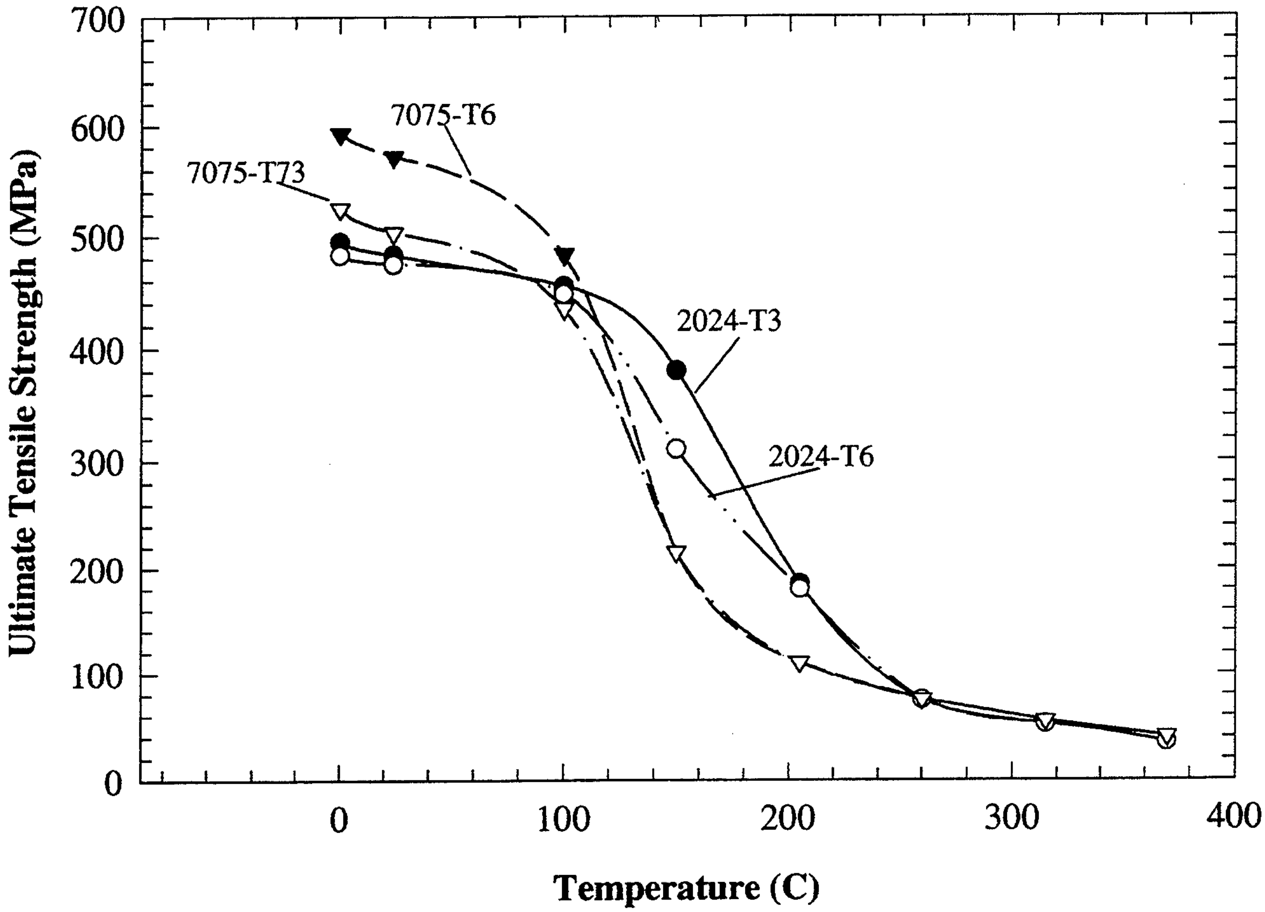


Fig. 37 – Ultimate tensile strength for aluminum alloys. Data from reference [22]

Table 22. Dimensions of Naval Aircraft

Plane	Ht (Overall)		Bottom Fuselage		Top of Fuselage		Bottom of Wing	
(Model)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)
TA-4F/J	4.75	15 ft. 7 in.	1.57	5 ft. 2 in.	3.20	10 ft. 6 in.	1.57	5 ft. 2 in.
EA-6B	5.08	16 ft. 8 in.	0.914	3 ft. 0 in.	3.05	10 ft. 0 in.	1.93	6 ft. 4 in.
A-6E	5.08	16 ft. 8 in.	1.22	4 ft. 0 in.	3.78	12 ft. 5 in.	2.39	7 ft. 10 in.
TC-4C	7.11	23 ft. 4 in.	0.914	3 ft. 0 in.	3.05	10 ft. 0 in.	0.61	2 ft. 0 in.
C-9B	8.38	27 ft. 6 in.	0.914	3 ft. 0 in.	4.52	14 ft. 10 in.	2.24	7 ft. 4 in.
UC-12B	4.42	14 ft. 6 in.	0.762	2 ft. 6 in.	2.74	9 ft. 0 in.	0.914	3 ft. 0 in.
C-130F	11.68	38 ft. 4 in.	0.61	2 ft. 0 in.	4.57	15 ft. 0 in.	4.27	14 ft. 0 in.
E-2C	5.59	18 ft. 4 in.	0.61	2 ft. 0 in.	2.74	9 ft. 0 in.	1.30	8 ft. 0 in.
QF-4N	5.03	16 ft. 6 in.	1.35	4 ft. 5 in.	3.35	11 ft. 0 in.	1.35	4 ft. 5 in.
F-14A	4.88	16 ft. 0 in.	1.22	4 ft. 0 in.	3.66	12 ft. 0 in.	2.06	6 ft. 9 in.
F/A-18A/B/C/D	4.65	15 ft. 3 in.	1.52	5 ft. 0 in.	3.20	10 ft. 6 in.	1.68	5 ft. 6 in.
F/A-18E/F	4.67	15 ft. 4 in.	1.30	4 ft. 3 in.	3.25	10 ft. 8 in.	2.13	7 ft. 0 in.
T-2C	4.52	14 ft. 10 in.	0.31	1 ft. 0 in.	2.29	7 ft. 6 in.	1.52	5 ft. 0 in.
T-34C	3.02	9 ft. 11 in.	0.762	2 ft. 6 in.	2.08	6 ft. 10 in.	1.22	4 ft. 0 in.
T-39D	4.88	16 ft. 0 in.	0.762	2 ft. 6 in.	3.35	11 ft. 0 in.	1.22	4 ft. 0 in.
T-44A	4.34	14 ft. 3 in.	0.914	3 ft. 0 in.	2.74	9 ft. 0 in.	1.91	6 ft. 3 in.
T-45A	4.09	13 ft. 5 in.	1.07	3 ft. 6 in.	2.79	9 ft. 2 in.	1.22	4 ft. 0 in.
B-52	14.73	48 ft. 4 in.	1.52	5 ft. 0 in.	5.33	17 ft. 6 in.	1.68	5 ft. 6 in.
F-4E	4.95	16 ft. 3 in.	1.83	6 ft. 0 in.	3.33	10 ft. 11 in.	1.83	6 ft. 0 in.
C-5A	19.86	65 ft. 2 in.	2.13	7 ft. 0 in.	9.32	30 ft. 7 in.	4.47	14 ft. 8 in.
C-130-H-30	11.66	38 ft. 3 in.	0.914	3 ft. 0 in.	4.57	15 ft. 0 in.	4.22	13 ft. 10 in.
AV-81	3.45	11 ft. 4 in.	1.32	4 ft. 4 in.	2.90	9 ft. 6 in.	1.02	3 ft. 4 in.

Tables 23 and 24 presents the model results for the times required to achieve a surface temperature of 100°C and 150°C for targets exposed to various size fires and positioned at three distances from the fire (3, 6.1, and 9.1 m (10, 20, and 30 ft)). The fires were assumed to be constant for all cases, except Case 5 in Table 23. The source profile was modified in Case 5 to be more realistic of the actual growth stage of the fire. The 10 MW fire was modeled as a linear ramp from 0.1 MW to 10 MW over the first 52 seconds and then constant at 10 MW. The growth period of 52 seconds was calculated based on a flame spread rate of 0.1 m/s [14] and a burning rate of 0.011 kg/m^2s (Figure 33) which corresponds to a heat release rate per unit area of 475 kW/m^2.

Table 23. Calculated Times to Achieve a Surface Temperature of 100°C on a 0.0081 m Thick Aluminum Target Exposed to a Fire Modeled as a Constant Point Source

Case	Heat release Rate (MW)	Distance Between Target and Fire Center		
		3.0 m (10 ft)	6.1 m (20 ft)	9.1 m (30 ft)
1	1	69 s	>300 s	>300 s
2	3	19 s	116 s	>300 s
3	6	9 s	43 s	144 s
4	10	6 s	24 s	62 s
5	ramp to 10 over 52 s then 10	24 s	50 s	89 s

Table 24. Calculated Times to Achieve a Surface Temperature of 150°C on a 0.0081 m Thick Aluminum Target Exposed to a Fire Modeled as a Constant Point Source

Case	Heat release Rate (MW)	Distance Between Target and Fire Center		
		3.0 m (10 ft)	6.1 m (20 ft)	9.1 m (30 ft)
1	1	155 s	>300 s	>300 s
2	3	30 s	>300 s	>300 s
3	6	14 s	76 s	>300 s
4	10	8 s	38 s	126 s
5	ramp to 10 over 52 s then 10	30 s	65 s	154 s

Tables 23 and 24 provide times to critical temperatures for varying exposure fires and distance from the fire. These data can be used to select appropriate detection times. The elements in a successful fire control scenario include time to: detect a fire, activate the suppression systems, discharge agent through the low level nozzles and control the fire. The time expected for a fire to be controlled by existing or proposed low level nozzles is on the order of 30 seconds, consistent with the criteria established in NFPA 409 [25].

The time to activate the AFFF system and discharge agent is dependent on the system design. Factors include time to activate valves/pumps and fill the system piping to the discharge nozzles. If systems are to prevent collateral damage from significant spills (e.g., spills creating a fire >1 MW), system activation must be rapid; otherwise detection time becomes less important. A system activation time on the order of 20 seconds was assumed for this analysis, based on discussions with NAVFAC on a reasonable system activation time. If a total of 50 seconds is required to activate the system and control the fire (20 sec activation time plus 30 sec fire control time), the detection time required to prevent collateral damage can be estimated.

Table 25 shows the time for critical failure (a range for 100-150°C failure temperature), accounting for the required time for activation and control. For a maximum detection time of 60 seconds, the analysis shows that collateral damage is unlikely to occur at a distance of 9.1 m (30 ft) for even large fires (i.e., a growing 10 MW fire). Similarly, targets within 6.1 m (20 ft) can be protected for smaller fires (< 6 MW) using the 60 second detection criteria. Assets within 3 m (10 ft) may or may not be damaged by relatively smaller fires (1 MW). Items within 3 m (10 ft) for fires larger than 1 MW are likely to be damaged.

Table 25. Range of Detection Times (sec) Required to Prevent Collateral Damage*

Fire Size (MW)	3 m (10 ft)	6.1 m (20 ft)	9.1 m (30 ft)
1	19-105	>300	>300
3	Damage[1]	66->300	>300
6	Damage	Damage - 26	94->300
Ramp to 10 over 52 s, then 10	Damage	Damage - 15	39-104

* Detection time accounts for a 50 s time for activation of suppression system and control of fire. Range corresponds to damage criteria of 100 and 150°C target surface temperatures.

[1] Damage to critical components likely.

An alternate, yet similar, modeling approach provides a more refined time limit. The transient heat transfer model was used with a continuously increasing source term (i.e., fire). It was assumed that a spill fire grows at a rate of 0.1 m/s and that the linear spread is equal to the diameter of the fire. The heat release rate was calculated from the area of the growing spill multiplied by the experimentally derived (i.e., from this test data) heat release rate per unit area of 475 kW/m^2. With this fire source term, the transient heat transfer model calculates that a target 9.1 m away will reach a surface temperature of 100°C in 77 seconds, at which time the fire size will be 22 MW, and will reach a temperature of 150°C in 90 s, at which time the fire will be 30 MW. Based on this potentially worst case growing spill fire, a maximum detection time of 60 seconds would not assure that collateral thermal damage would be prevented within 9.1 m (30 ft). This continuously growing spill fire case would require a 27 to 40 second detector response time, assuming the 50 s time for activation and control and 100 to 150°C damage criteria, respectively.

A review of the OFD response time results in Tables 9a-9f, shows that the best triple IR detector (OFD6) was able to detect all fires greater than 250 kW in 16 to 49 seconds at any detector orientation and location tested. These detection times include both unobstructed and obstructed fire scenarios. For unobstructed fire scenarios, the response times ranged from 16 to 38 s. The detection times achieved by OFD6, and also those achieved by other detector models (e.g., OFD3 and OFD1), are consistent with being able to prevent collateral thermal damage at distances greater than 9.1 m for steady-state fires of up to 10 MW and even for a continuously growing spill fire. Given the conservatism of the heat transfer model and the results of Table 25, the current optical fire detection technologies appear to be capable of meeting the intent of the Navy to limit collateral damage.

The detection times of the quickest responding detectors (3IR) for the DLS 250 kW and larger fires ranged from 16-49 s. Although minimum detection times are desirable, it is prudent to provide a certain degree of performance flexibility in establishing specification criteria. This flexibility recognizes test variability and repeatability. The results of thermal damage modeling and the detector alarm time results presented in Tables 9a-9f suggest that detector response time criteria of 45 seconds for a 250 kW unobstructed fire in direct line of sight (DLS) of the detector, and 50 seconds for a 900 kW fire (obstructed or unobstructed) at any location up to 45.7 m (150 ft) or detector orientation evaluated (DLS or 40 degrees off-axis) provides a reasonable degree of performance. These detector response criteria will provide for relatively rapid detection of most fires while minimizing or preventing thermal collateral damage when combined with a suitable fire suppression system.

9.0 SUMMARY AND CONCLUSIONS

Tests were conducted to evaluate the level of performance of commercially available optical fire detectors (OFD) for use in Navy hangars. Detectors were evaluated based on response to fuel spill fires and to optical stresses (i.e., potential false alarm sources). A summary of key findings include:

1. The Navy requirement of using only UV/IR optical fire detectors is not warranted with the current technologies. The use of multiple (triple) spectrum IR detectors can provide improved detection and false alarm immunity over available IR and UV/IR detectors.

2. A relative rank ordering of the OFDs was determined based on the ability of detectors to alarm to the wide range of test scenarios conducted. The results clearly identify OFD6 (3-IR) as the best performer. Detector models OFD1 (UV/IR), OFD3 (3-IR), and OFD4 (2-IR) had mixed results depending on the fire scenarios and test conditions. Detectors OFD2 and OFD5 (both UV/IR) exhibited the greatest limitations.

3. The rank order of performance of the OFDs to the optical stresses is in good agreement with the fire test results. The OFD models OFD3 and 6 (3-IR) responded to a very limited number of nuisance source test conditions. OFD1 (UV/IR) and OFD4 (2-IR) responded to a range of test conditions, and OFD2 and 5 (UV/IR) responded to a wider

conditions. The models that performed best in the fire tests, also performed well with respect to nuisance alarm immunity.

4. The use of JP-8 compared to gasoline pan fires provided a greater challenge to the optical fire detectors. Based on the tests conducted in this program, there is not a clear recommendation on whether to use JP-8 or JP-5 for performance testing. The use of JP-5 may provide a slightly greater challenge to some detectors with respect to the ability to detect a fire, however JP-8 may be in greater use in the field and more representative of typical hazards.

5. Optical fire detectors were not sensitive to fuel spill geometry for the fires tested.

6. Unconfined spill fire test scenarios were quite repeatable as measured by OFD responses and fire heat release rate measurements. The size of the continuously flowing unconfined spill fires are primarily dependent on the fuel flow rate. The concrete temperature has a minor second order effect, which decreases with increasing fuel flow rate.

7. The test results indicate that the fixed quantity spill fire scenarios are dependent on the physical structure of the surface (i.e., levelness, surface coating, porosity, surface roughness) and the temperature of the surface as well as the fuel. The surface features impact pool shape and depth and have a significant effect on fire growth rate and ultimate size. Contrary to the continuously flowing unconfined spill scenarios, temperature variations have a direct effect on fire growth rate and size. Repeatable fixed quantity spill fire tests would require special attention to maintain uniform surface features and temperatures.

8. For all fire scenarios evaluated, detector alarm times were directly correlated with the heat release rate of the fires conducted (~100 to 1000 kW). Faster response times were typically achieved with larger fires.

9. Based on the limited comparative test data, it is unclear whether the unconfined spill fires provide a unique challenge to the OFDs compared to pan fires. Therefore, the use of pan fires in a detector performance specification test may be adequate. The primary advantage of using pan fires is simplicity of equipment setup and test procedure. Also special test surfaces are not required as with the unconfined spill fire scenarios. In addition, there are environmental clean-up advantages of using pan fires rather than spill fires.

10. The mass burning rates per unit area for the spill fires were approximately 20 to 25 percent of the published data for pool fires. Because of the much smaller burning rates for these spill fires, it was also observed that the pool diameters for the spill fires were approximately twice as large as would typically be calculated (using published correlations and data) for pool fires of the same heat release rate.

11. Based on a conservative transient heat transfer model, it is believed that an acceptable level of collateral thermal damage to aircraft (i.e., no damage to aircraft greater than 9.1 m

from the fire center) can be achieved with an optical fire detection system and low level AFFF system that can control a fire within 90 seconds of ignition.

10.0 RECOMMENDATIONS FOR PERFORMANCE SPECIFICATION

Based on a consideration of Navy requirements for fire protection in hangars, the results of this study, and a review of previous test programs, e.g. reference [1] and other unpublished studies, a performance specification has been drafted for evaluating and approving optical fire detectors for use in Navy aircraft hangars. The performance specification includes two primary sections, which are addressed in this report: 1) Fire Test Specifications; and 2) Optical Stress Immunity Test Specifications. A copy of the draft performance specification is included as Appendix G.

The draft performance specification was developed from a performance specification for optical fire detectors prepared in 1994 by the National Research Council of Canada (NRC) and Leber/Rubes Inc. (LRI) for the Canadian Department of National Defense, Air Command (DND). The section on optical stress immunity testing follows closely the initial specification by NRC with modifications based on the recommendations from the testing performed as part of this program (Appendix C). The section on fire testing is based largely on the fire testing and analysis presented in this report.

The justification for the fire specification tests and alarm criteria are presented below:

1. OFDs should be tested at distances of 30.5 m (100 ft) and 45.7 m (150 ft) to be consistent with intended use in Navy hangars.

2. OFDs should be mounted at a height of 3.0 m (10 ft) to be consistent with intended use in Navy hangars. This height is representative of typical installations.

3. OFDs should tested in two orientations: 1) the OFD should be aimed at a point 1.22 m (4 ft) above the center of the fire so that fire source is in direct line of sight (DLS) of the detector, and 2) the OFD should be aimed at an angle of 40 degrees in the horizontal field of view with respect to a point 1.22 m (4 ft) above the center of the test fire. A point 1.22 m above the fire is consistent with typical mid-heights of the fires to be tested. Detectors should be tested at both orientations in order to characterize the performance capability over a reasonable field of view. Test results indicated little difference between detector performance at the horizontal off-axis (HOA) and horizontal and vertical off-axis (HVOA) detector orientations.

4. Pan fires are recommended for use in the performance specification tests, primarily on the basis that they are easier and less expensive to conduct than unconfined spill fire scenarios and because the test results did not demonstrate that spill fires provided a unique challenge to OFDs. However, it is noted that due to limited comparative test data, it is unclear whether this conclusion is fully valid. The fact that OFD responses were well correlated

with the heat release rate of the fires conducted (~100 to 1000 kW) and insensitive to fuel spill geometry for the fires tested, also supports the conclusion that the use of pan fires is adequate.

Appendix H contains calculations for determining the pan sizes presented in the draft test specification. The pans were sized to provide equivalent fires as the unconfined spill fire scenarios. Pan fire fuel burning rate data obtained from this test program was used in these calculations.

5. A pan fire of 250 kW was chosen as a minimum fire size that should be detectable at both 30.5 m (100 ft) and 45.7 m (150 ft) distances.

6. A pan fire of 900 kW (i.e., the largest fire scenario conducted in this test program) was also included in the test specification because it provides a sufficient size fire to be used with an obstruction. This obstructed fire is a reasonable and realistic test scenario to define detector capabilities at all locations and orientations. It also provides a test for acceptable alarm responses which are consistent with the collateral damage objectives.

7. It is recommended that JP-8 fuel be used in the performance testing because it is the most widely used military fuel. In addition, the criteria established in this performance specification are primarily based on the results of the JP-8 fire test results. Therefore, the basis for the tests is well established and documented. The results of this test program did not show a clear advantage of using JP-8 or JP-5 as the test fuel.

8. The ignition source should consist of a shielded acetylene torch flame. The flame should be approximately 25 cm long and 5 cm in diameter. The flame should be shielded from the detectors using a metal plate or shroud attached to the torch. This ignition source was effective in the fire tests conducted.

9. One performance specification test scenario should consist of using a chopped UV/IR source in conjunction with the 250 kW fire. The test results showed that this source provided a means of evaluating whether OFD detection performance may be hindered by a potential nuisance source that could be found in a Navy hangar. This source prevented several detectors from alarming when exposed to a spill fire (Section 6.6.1). The 250 kW fire was selected because the test results indicate that the chopped UV/IR source poses a greater impediment to detection of smaller fires.

   The chopped UV/IR source should consist of a set of three, 500 W halogen work lamps with the glass covers removed. Chopping should be achieved by rotating a segmented drum around the axis of the row of lamps positioned horizontal to the ground. The chopping frequency should be 4 to 5 Hz. The lamps should be angled to face directly at the detectors. The chopped UV/IR source should be positioned at 10 m from the OFD, in-line between the OFD and the fire.

10. One performance specification test scenario should consist of using a chopped IR source in conjunction with the 900 kW fire. The test results showed that this source provided a means of evaluating whether OFD detection performance may be hindered by a potential nuisance source that could be found in a Navy hangar. This source prevented several detectors from alarming when exposed to a spill fire (Section 6.6.2). Both the UV/IR and the IR sources should be tested because they affect different OFD technologies. The 900 kW fire was selected because the test results indicated the chopped IR source prevented more alarms with this size fire and also caused significant delays in alarm times (approximately 10 to 30 s).

    The chopped IR source should consist of a 1500 W quartz heater. Chopping should be achieved by rotating a segmented drum around the axis of the heating element when positioned horizontal to the ground. The chopping frequency should be 4 to 5 Hz. The heating element should be fully visible to the OFD. The chopped IR source should be positioned at 10 m from the OFD, in-line between the OFD and the fire. The position of the source is consistent with the test setup evaluated in this test program called "Chopped IR at 20 m."

11. One performance specification test scenario should consist of using an obstruction to block a portion of the 900 kW fire from the view of the OFD. The obstruction should block all of the flame from a height of 0.3 to 2.3 m above the top edge of the pan. This test scenario represents a plausible condition that may be found in a Navy hangar incident. The test results also indicate that this test scenario provided a means of evaluating the limits of OFD detection performance. Based on the testing performed, the raised obstruction (i.e., 0.3 to 2.3 m high) was slightly more challenging than the obstruction that covered the base of the fire (i.e, 0 to 1.3 m high) (see Sections 6.67 to 6.6.10). Test scenarios in which the obstruction was moved during the course of the fire provided little additional insights compared to the stationary obstruction tests.

12. The inclusion of an arc welding source in the detectors field of view with a fire event proved to be marginally useful in establishing how well detectors could discriminate between nuisance sources and real fires while also detecting real fires (Section 6.6.5 and 6.6.6). These tests only presented problems for OFD1 (UV/IR) with the 100 kW fires and for OFD2 (UV/IR) with the 1000 kW fire. With larger fires (i.e., ~1000 kW), OFD1 was unaffected by the welding. Detector model OFD2 had overall poor performance even without the welding event; the inclusion of the welding would not be the difference of approving or not approving this OFD. Since welding and other hot work are prohibited events in Navy hangars, these test scenarios are not recommended for inclusion in the performance specification tests. This will also minimize the number of tests conducted.

    If the an arc welding event is still desired, it should consist of a man using an arc welder set to 100A and a 6013, 0.318 cm (1/8 in.) organic binder rod along a piece of steel set on the floor (based on test results, see Sec. 6.6.6). During the test, two welding rods should be used in succession with no more than a 20 second down time in between changing the rods. Welding should begin prior to but no more than 10 seconds before

ignition. The welding should take place 16 m from the OFD, in-line between the OFD and the fire. There should be no obstructions between the welding source and the OFD.

13. Based on the OFD test results and the analysis presented in Section 8 for assessing collateral thermal damage, fire test scenarios and detector response time criteria were identified for the performance specification.. Table 26 shows a summary of the tests and alarm criteria. The tests selected are discussed in items 5-10 above. The alarm criteria were established based on the conservative thermal damage assessment and the capabilities of the current state-of-the-art detector technologies. At a minimum, OFDs should be able to detect a 250 kW fire in its direct line of sight within 45 s at both 30.5 m and 45.7 m distances away from the fire (Test 1). This response time will assure that no thermal damage will occur to aircraft more than 9.1 m from the fire center given the assumptions in the analysis. Under many scenarios, no collateral damage would be expected in ranges greater than 9.1 m.

Table 26. Recommended Fire Exposure Tests and Alarm Criteria

No.	Fire	Test Scenario	Alarm Criteria
1	0.48 x 0.48 m JP-8 pan fire	Unobstructed	$\leq$ 45 s at 30.5 m DLS and 45.7 m DLS
2	0.91 x 0.91 m JP-8 pan fire	Obstructed 0.3 to 2.3 m above lip of pan.	$\leq$ 50 s at all locations and orientations
3	0.48 x 0.48 m JP-8 pan fire	Chopped UV/IR source in field of view	$\leq$ 45 s at 30.5 m DLS and 45.7 m DLS
4	0.91 x 0.91 m JP-8 pan fire	Chopped IR source in field of view	$\leq$ 50 s at all locations and orientations
5	0.91 x 0.91 m JP-8 pan fire	Welding in field of view	$\leq$ 50 s at all locations and orientations

Since Test 3 also consists of a 250 kW fire with only the addition of chopped UV/IR source, the alarm criteria is the same as for Test 1. The inclusion of the optical source should not affect the performance of the OFD.

For Tests 2 and 4, a detector is required to alarm within 50 s at all distances and orientations tested when exposed to a 900 kW fire. This alarm time criteria applies for both the obstructed fire (Test 2) and the unobstructed fire with the chopped IR source (Test 4). Detection of a 900 kW fire within 50 s should provide the limited thermal damage discussed in Section 8. Current OFD technology is capable of achieving this performance.

The analysis in Section 8 indicated that the maximum alarm time for a worst case, continuously growing spill fire ranged from 27 to 40 s. Although the maximum alarm times established for the performance specifications are higher, it must be realized that the criteria is for much smaller fires (i.e., 250 and 900 kW fires rather than 22 to 30 MW

fires for the worst case scenario). If the fire was actually growing according to the worst case fire growth profile, OFD responses would be expected to be much quicker. The test results showed that alarm times were directly correlated with the heat release rate of the fires conducted (~100 to 1000 kW). Faster response times were typically achieved with larger fires. The alarm time criteria established in the recommended performance test specification meets the objectives of minimizing collateral thermal damage and identifying the best detectors to use in Navy hangar applications.

In conclusion, the test specification addresses OFD performance in detecting fires within suitable time limits and immunity to potential false alarm sources. Not all aspects of the spill fires examined and the test specification could be examined in depth during this program. Consequently, the proposed test specification may require modification as new information becomes available.

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Appendix A

Instrumentation List for Fire Tests

Table A1. Instrumentation List (Item Number Corresponds to Column in Output File)

Item #	Variable Name	Description	Location
1	Time	Time from start of data acquisition (s)	
2	PoolX	Resistance wire detection in X direction (V)	Fire size in the direction perpendicular to OFD DLS
3	PoolY	Resistance wire detection in Y direction (V)	Fire size in the direction parallel to OFD DLS
4	OFD1A	UV/IR	30.5 m Direct line of sight
5	OFD2A	UV/IR	30.5 m Direct line of sight
6	OFD3A	Triple IR	30.5 m Direct line of sight
7	OFD4A	Dual IR	30.5 m Direct line of sight
8	OFD5A	UV/IR	30.5 m Direct line of sight
9	OFD6A	Triple IR	30.5 m Direct line of sight
10	OFD1B	UV/IR	30.5 m Horizontal off-axis
11	OFD2B	UV/IR	30.5 m Horizontal off-axis
12	OFD3B	Triple IR	30.5 m Horizontal off-axis
13	OFD4B	Dual IR	30.5 m Horizontal off-axis
14	OFD5B	UV/IR	30.5 m Horizontal off-axis
15	OFD6B	Triple IR	30.5 m Horizontal off-axis
16	OFD1C	UV/IR	30.5 m Horizontal and vertical off-axis
17	OFD2C	UV/IR	30.5 m Horizontal and vertical off-axis
18	OFD3C	Triple IR	30.5 m Horizontal and vertical off-axis
19	OFD4C	Dual IR	30.5 m Horizontal and vertical off-axis
20	OFD5C	UV/IR	30.5 m Horizontal and vertical off-axis
21	OFD6C	Triple IR	30.5 m Horizontal and vertical off-axis
22	OFD1D	UV/IR	45.8 m Direct line of sight
23	OFD2D	UV/IR	45.8 m Direct line of sight
24	OFD3D	Triple IR	45.8 m Direct line of sight
25	OFD4D	Dual IR	45.8 m Direct line of sight
26	OFD5D	UV/IR	45.8 m Direct line of sight
27	OFD6D	Triple IR	45.8 m Direct line of sight
28	OFD1E	UV/IR	45.8 m Horizontal off-axis
29	OFD2E	UV/IR	45.8 m Horizontal off-axis
30	OFD3E	Triple IR	45.8 m Horizontal off-axis
31	OFD4E	Dual IR	45.8 m Horizontal off-axis
32	OFD5E	UV/IR	45.8 m Horizontal off-axis
33	OFD6E	Triple IR	45.8 m Horizontal off-axis
34	OFD1F	UV/IR	45.8 m Horizontal and vertical off-axis
35	OFD2F	UV/IR	45.8 m Horizontal and vertical off-axis
36	OFD3F	Triple IR	45.8 m Horizontal and vertical off-axis
37	OFD4F	Dual IR	45.8 m Horizontal and vertical off-axis
38	OFD5F	UV/IR	45.8 m Horizontal and vertical off-axis
39	OFD6F	Triple IR	45.8 m Horizontal and vertical off-axis

Table A1. Instrumentation List (Item Number Corresponds to Column in Output File (Continued)

Item #	Variable Name	Description	Location
40	Fault4A	Dual IR Fault	30.5 m Direct line of sight
41	Fault4B	Dual IR Fault	30.5 m Horizontal off-axis
42	Fault4C	Dual IR Fault	30.5 m Horizontal and vertical off-axis
43	Fault4D	Dual IR Fault	45.8 m Direct line of sight
44	Fault4E	Dual IR Fault	45.8 m Horizontal off-axis
45	Fault4F	Dual IR Fault	45.8 m Horizontal and vertical off-axis
46	HF1	Heat flux meter Medtherm # 65609 (50 kW/m^2)	1 m from pad center, 1.2 m high, volts x 5959 = kW/m^2
47	HF2	Heat flux meter Medtherm # 57497 (20 kW/m^2)	2 m from pad center, 1.2 m high, volts x 2202 = kW/m^2
48	HF3	Heat flux meter Medtherm # 57496 (20 kW/m^2)	3 m from pad center, 1.2 m high, volts x 2270 = kW/m^2
49	HF4	Heat flux meter Medtherm # 65601 (50 kW/m^2)	2 m from pad center, 0.6 m high, volts x 5789 = kW/m^2
50	HF5	Heat flux meter Medtherm # 659113 (20 kW/m^2)	3 m from pad center, 1.2 m high, volts x 1385 = kW/m^2
51	HF6	Heat flux meter Medtherm # 659115 (20 kW/m^2)	4 m from pad center, 1.8 m high, volts x 1419 = kW/m^2
52	HF7	Heat flux meter Medtherm # 659114 (20 kW/m^2)	5 m from pad center, 2.4 m high, volts x 1544 = kW/m^2
53	TC1	Thermocouple (C)	Front temp. of 0.032 Al sample at 1 m
54	TC2	Thermocouple (C)	Back temp. of 0.032 Al sample at 1 m
55	TC3	Thermocouple (C)	Front temp. of 0.063 Al sample at 1 m
56	TC4	Thermocouple (C)	Back temp. of 0.063 Al sample at 1 m
57	TC5	Thermocouple (C)	Front temp. of 0.063 Al sample at 2 m
58	TC6	Thermocouple (C)	Back temp. of 0.063 Al sample at 2 m
59	TC7	Thermocouple (C)	Front temp. of 0.032 Al sample at 3 m
60	TC8	Thermocouple (C)	Back temp. of 0.032 Al sample at 3 m
61	TC9	Thermocouple (C)	Front temp. of 0.063 Al sample at 3 m
62	TC10	Thermocouple (C)	Back temp. of 0.063 Al sample at 3 m
63	TC11	Thermocouple (C)	Front temp. of 0.063 Al sample at 2 m, 0.6 m height
64	TC12	Thermocouple (C)	Back temp. of 0.063 Al sample at 2 m, 0.6 m height
65	TC13	Thermocouple (C)	Front temp. of 0.063 Al sample at 2 m, 2.4 m height
66	TC14	Thermocouple (C)	Back temp. of 0.063 Al sample at 2 m, 2.4 m height
67	TC15	Thermocouple (C)	In slab temp., position A
68	TC16	Thermocouple (C)	In slab temp., position B
69	TC17	Thermocouple (C)	In slab temp., position C
70	TC18	Thermocouple (C)	In slab temp., position D
71	TC19	Thermocouple (C)	In slab temp., position E

Table A1. Instrumentation List (Item Number Corresponds to Column in Output File (Continued)

Item #	Variable Name	Description	Location
72	TC20	Thermocouple (C)	Slab surface temp., position A
73	TC21	Thermocouple (C)	Slab surface temp., position B
74	TC22	Thermocouple (C)	Slab surface temp., position C
75	TC23	Thermocouple (C)	Slab surface temp., position D
76	TC24	Thermocouple (C)	Slab surface temp., position E
77	TC25	Thermocouple (C)	Fuel Temperature
78	IR	Pyroelectric detector (with chopper) (V)	IR detector for the CO2 peak at ~4.3 micron, at 4.? m
79	Visible	Photodiode (V)	Visible spectrum detector, at 45.8 m
80	FuelWt	Counter balance scale	Fuel supply tank scale, 0-50 lb = 0-5 V
81	CO	CO/CO2 Siemens Ultramat 22P, BO-951	Hood duct gas concentration, 0-1% = 0-20 ma
82	CO2	CO/CO2 Siemens Ultramat 22P, BO-951	Hood duct gas concentration, 0-4% CO2 = 0-20 ma
83	O2	Siemens Oxymat 5E, BO2-903	Hood duct gas concentration, 0-25% O2 = 0-20 ma
84	Pressure	Neotronics micromanometer, MP6KP	Duct velocity pressure. 0-2 volts = 0-2 inches of water
85	TC 26	Thermocouple	Duct temperature
86	TC 27	Thermocouple	Duct temperature

Appendix B

NRC Internal Report No. 773
"The Use of Ni-chrome Ribbon Wire to Determine the Dimensions of Unconfined Flammable Liquid Spill Fires"

National Research Council Canada
Conseil national de recherches Canada

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The Use of Ni-Chrome Ribbon Wire to Determine the Dimensions of Unconfined Flammable Liquid Spill Fires

George P. Crampton

Internal Report No. 773

Date of Issue: November, 1998

Published by
Institute for Research in Construction

IRC

THE USE OF NI-CHROME RIBBON WIRE TO DETERMINE THE DIMENSIONS OF UNCONFINED FLAMMABLE LIQUID SPILL FIRES

by

George P. Crampton

ABSTRACT

As part of a test series to evaluate the performance of optical flame detectors, it was necessary to develop a system to determine the size of unconfined flammable liquid spill fires. A system using Ni-chrome wire was developed to directly measure the surface or horizontal flame dimension in both the "X" and "Y" directions, assuming that the fire was oval in shape. The method is described in this report. Also discussed are the electrical circuit used for the measurements, the calibration procedures, test results and the limitations of the system.

INTRODUCTION

In July 1998, a series of hydrocarbon fuel fire tests were conducted at the National Research Council full-scale test facility located near Almonte, Ontario. These tests were part of a joint research project with Hughes Associates Inc. (HAI) and the Naval Facilities Engineering Command (NAVFAC), US Navy to evaluate the performance of optical fire detectors for use in US military aircraft hangers. For this project, it was necessary to develop a system to determine the size of unconfined flammable liquid spill fires.

There are limitations to the existing methods for determining the size of a fire. The fast changing dimensions of the spill fires and the large number of tests made determining the fire size using video grid analysis both subjective and time consuming Visual observations could also be deceiving since continuous fueling with cold fuel in the centre of the spill fire can produce a halo burn which resembles a full fire but produces significantly lower radiation and heat output. A method to directly measure the surface or horizontal flame dimension in both the "X" and "Y" directions, assuming that the fire was oval in shape, was developed for the test series. The results obtained using this system were used to supplement the estimates of the fire dimensions determined using video grid analysis and visual observations.

The electrical resistance of Ni-chrome wire increases slightly when heated [1,2]. The change in resistance is proportional to the length of the wire in the flame and the flame temperature. However, the flame temperature is dependent on the burning characteristics of the fuel. For the method outlined in this report, it was assumed that the flame temperature is constant. Based on this principle, a circuit can be used to null the overall resistance of the wire and produce an output voltage proportional to the length of wire in direct contact with the flame. For this project, two wires were used to bisect the spill fire in the "X" and "Y" directions. Using this system, a real time record of the fire dimension was obtained.

This report describes the method and circuitry used to determine fire dimensions using Ni-chrome ribbon wire. It discusses calibration procedures, test results and the limitations of the system used.

SYSTEM DESIGN

For this project, fire sizes up to 2.5 m in diameter were expected. A 3 m by 3 m test frame was constructed using 19 mm diameter steel electrical conduit. This frame provided a mount for the two Ni-chrome wires oriented in the "X" and "Y" directions (Figure 1).

Ni-chrome ribbon, 0.4 mm thick by 0.18 mm wide, with a nominal electrical resistance of 16 Ω/m was used. Ribbon was chosen instead of round wire to achieve both increased strength and quicker response.

Due to the expansion of the wire when heated, a spring was required to take up any slack. The strength of the spring was selected so that it would not stretch the heated portion of the wire destroying its ability to return to its original length and electrical resistance. A 3 m steel measuring tape was used as the spring.

The moveable end of the measuring tape was fitted with a ceramic insulator, as was the fixed end of the wire on the opposite side of the frame. This electrically isolated the wire from the steel frame.

The steel tape and the insulated end of the Ni-chrome wire were connected to the metal frame (Figure 1). This setup was repeated for the wire in the other direction. This wire was raised 10 mm so there would be no electrical contact where the wires crossed at the centre of the frame.

CIRCUIT DESIGN

The total resistance of each wire was measured to be 50 Ω. To null out this resistance, a bridge circuit was constructed (Figure 2). One side of the bridge consisted of a 56 Ω resistor in series with the 50 ohm Ni-chrome wire. The other side of the bridge consisted of a 5.6 kΩ resistor in series with a 1 kΩ potentiometer and a second 5.6 kΩ resistor. Both sides of the bridge were connected across a Hewlett Packard, Model 6205C*, variable voltage power supply.

The 1 kΩ potentiometer was used to balance the bridge and reduce the voltage difference between the Ni-chrome ribbon wire and the 5.6 kΩ resistor to zero. Any resistance change on the wire due to heating produced a voltage at the bridge.

By varying the supply voltage, the system could be calibrated to provide an output proportional to the length of the heated portion of the wire. That is, "x" mV/m of heated wire.

* Certain commercial products are identified in this report in order to adequately specify the experimental procedure. In no case does such identification imply recommendations or endorsement by the National Research Council, nor does it imply that the product or material identified is the best available for the purpose.

For the system to work properly, it is important that all electrical connections in the bridge circuit be mechanically and electrically solid using crimp lugs or screw down terminal strips. Any small resistance changes will greatly affect the results.

CALIBRATION

Before calibrating the system, the ribbon wires were electrically preheated using a 120 V AC source. A dimmer switch was used to limit the current through the wire. The dimmer switch was turned up until the wire glowed red. This was repeated a few times to condition the wire prior to testing.

Three shallow rectangular pans with a 25 mm lip height were used to calibrate the system. The pans were 1.12 m by 0.3 m, 0.56 m by 0.3 m and 0.28 m by 0.3 m. They were arranged individually and end-to-end to provide linear flame dimensions of 0.28 m, 0.56 m, 1.12 m and 1.96 m. The power supply for the bridge circuit was adjusted to 2.81 V, which produced an output of 10 mV/m of flame when JP-8 was used as the fuel (Figure 3).

The results shown in Figure 3 also indicate that the system is stable. There is minimal variation in the system output once the flame is fully developed over the entire length of the pan. The variation in the signal output is most likely due to two factors:

1. Variations in the flame temperature.
2. Variations in flame dimensions with air entrainment at the pan lip.

LIMITATIONS

The output of the system is calibrated assuming an average voltage per length of wire involved in flame and a constant flame temperature. Flame temperature and heat transfer to the wire is dependent on the fuel type. The system should be calibrated using the specific fuel under investigation.

The test arrangement with two crossed wires as shown in Figure 1 assumes that the spill fire will develop in a circular or oval shape that is centered on the "X" and "Y" intercept. Should the spill fire develop off axis, one or both of the outputs will read low since the widest part of the fire will not be measured. A system with improved accuracy could be developed using a grid of uniformly spaced wires.

For the fire tests conducted as part of the joint project with HAI and NAVFAC, the primary interest was the flame dimensions during the fire growth stage for use in determining flame size at the time the optical flame detectors responded to the fire. The system was, therefore, calibrated for the initial stages of fire growth, typically less than 1 min. When the fires are allowed to reach steady state, the flame temperature and the heat output increase significantly. As shown in Figure 4 for a test with a 0.6 m by 0.6 m pan fire with JP-8, the output of the system varies with the flame characteristics. The system could be used to determine the heat release rate if calibrated for this purpose. The heat release rate shown in Figure 4 was measured using an oxygen depletion calorimeter.

The output of the Ni-chrome wire system does not always return to 0 V after a fire test. The largest variation encountered in the more than 100 tests conducted with

the system was 2 mV or 0.2 m. This was due in part to the rapid extinguishment of the fire and soaking of the wire using a foam water extinguisher. Although this effect is not cumulative, a re-zeroing of the bridge is recommended before each test. The zeroing does not affect the calibration, which is determined by the supply voltage.

SUMMARY

In this report, the method and circuitry used to determine fire dimensions using Ni-chrome ribbon wire are described. The calibration procedures, limited test results and the limitations of the system are discussed. The results indicate that the system can be used to provide time-dependent estimates of the dimensions of spill fires. The system was used for the test series for the joint research project with HAI and NAVFAC. The results will be used to supplement and complement flame dimensions determined using video grid analysis and visual observations.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Gary Lougheed, Bruce Taber, Cameron McCartney, Vic Fortington, Michael Ryan and Michael Wright of the Fire Risk Management Program and Dr. Daniel Gottuk of Hughes Associates, Inc. for their contributions to this report.

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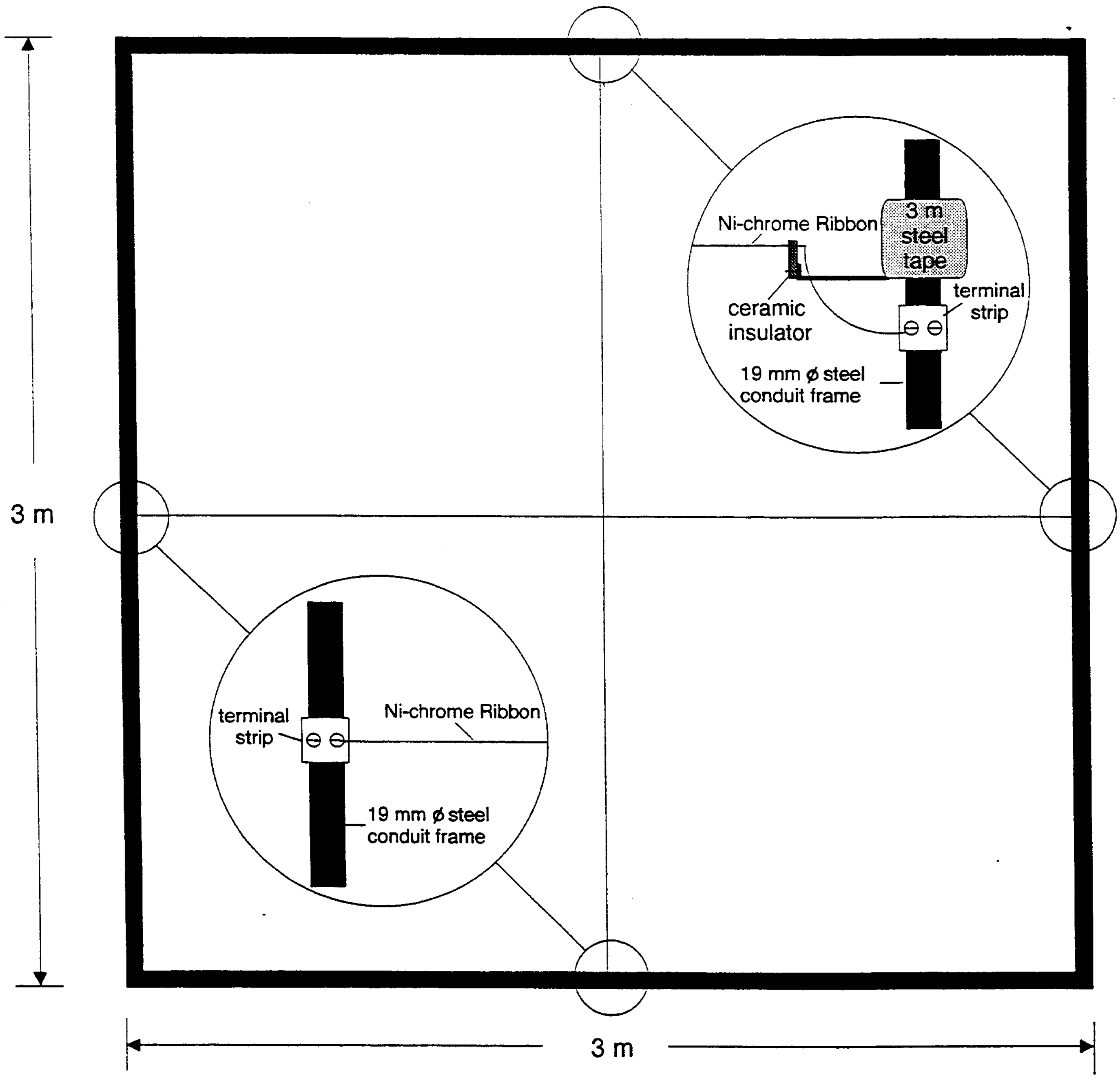


Figure 1. Plan View of Ni-chrome wire mounting hardware and support frame.

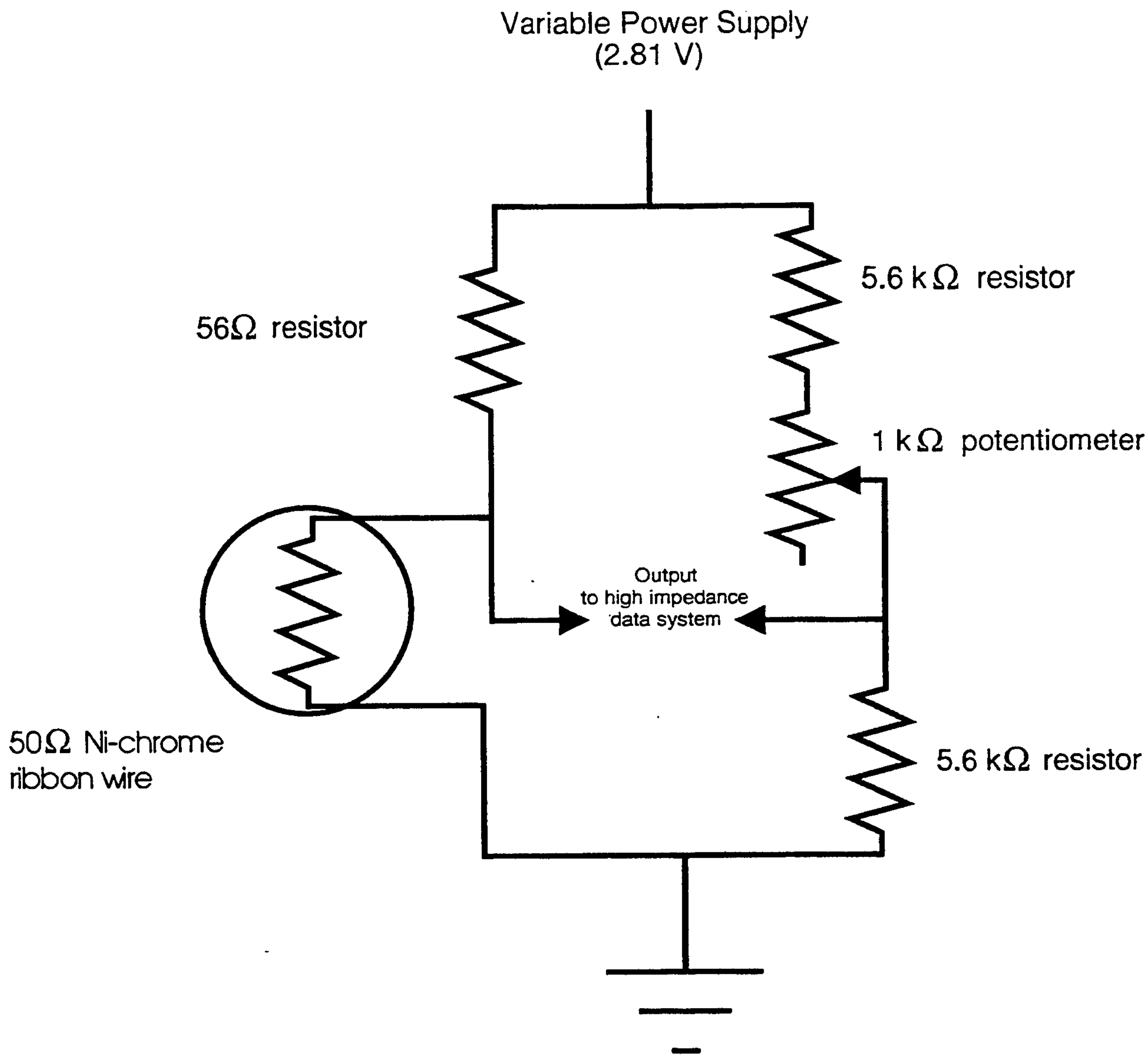


Figure 2. Bridge circuit diagram.

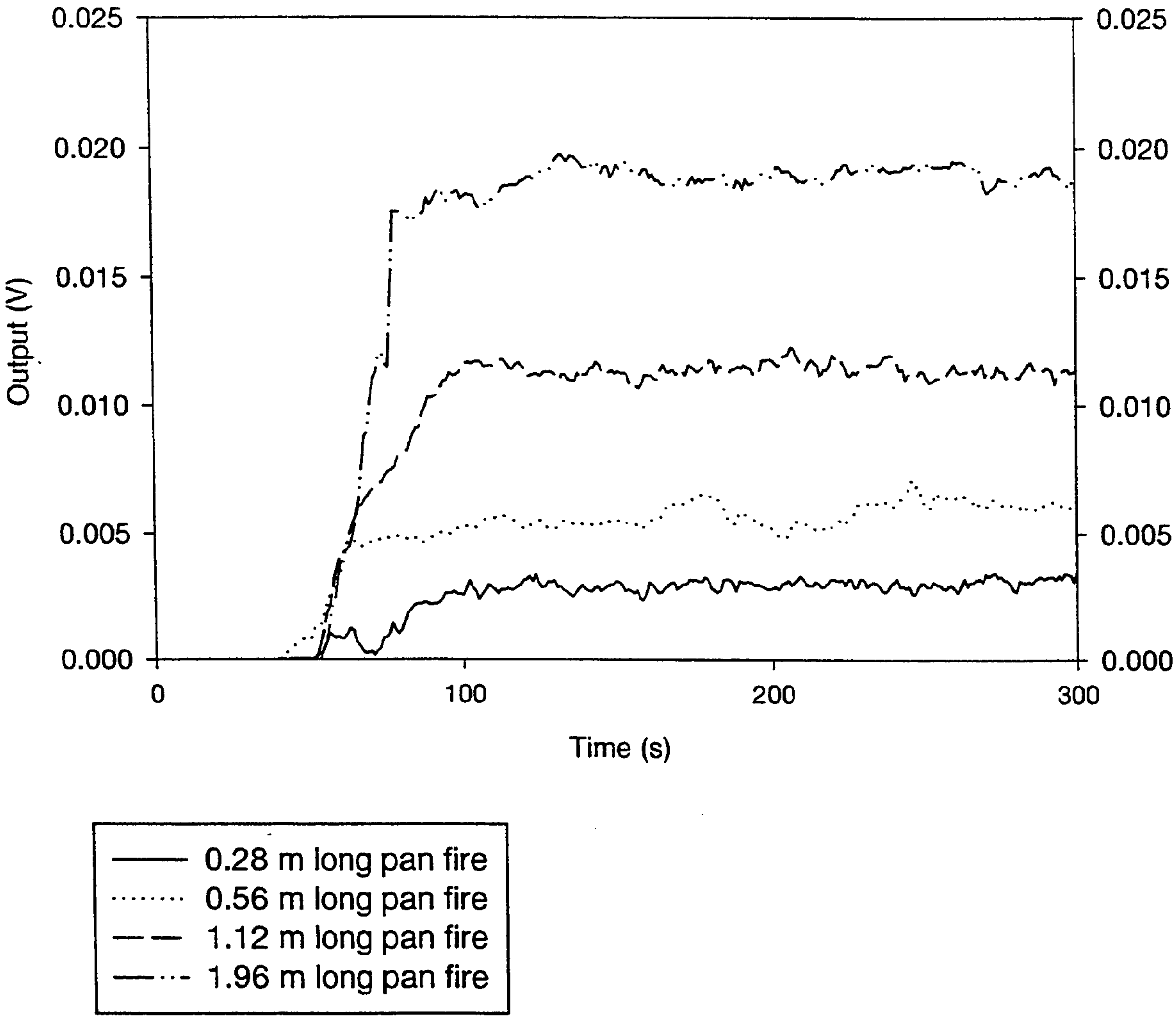


Figure 3. Circuit output (V) versus time for 4 pan fire lengths.

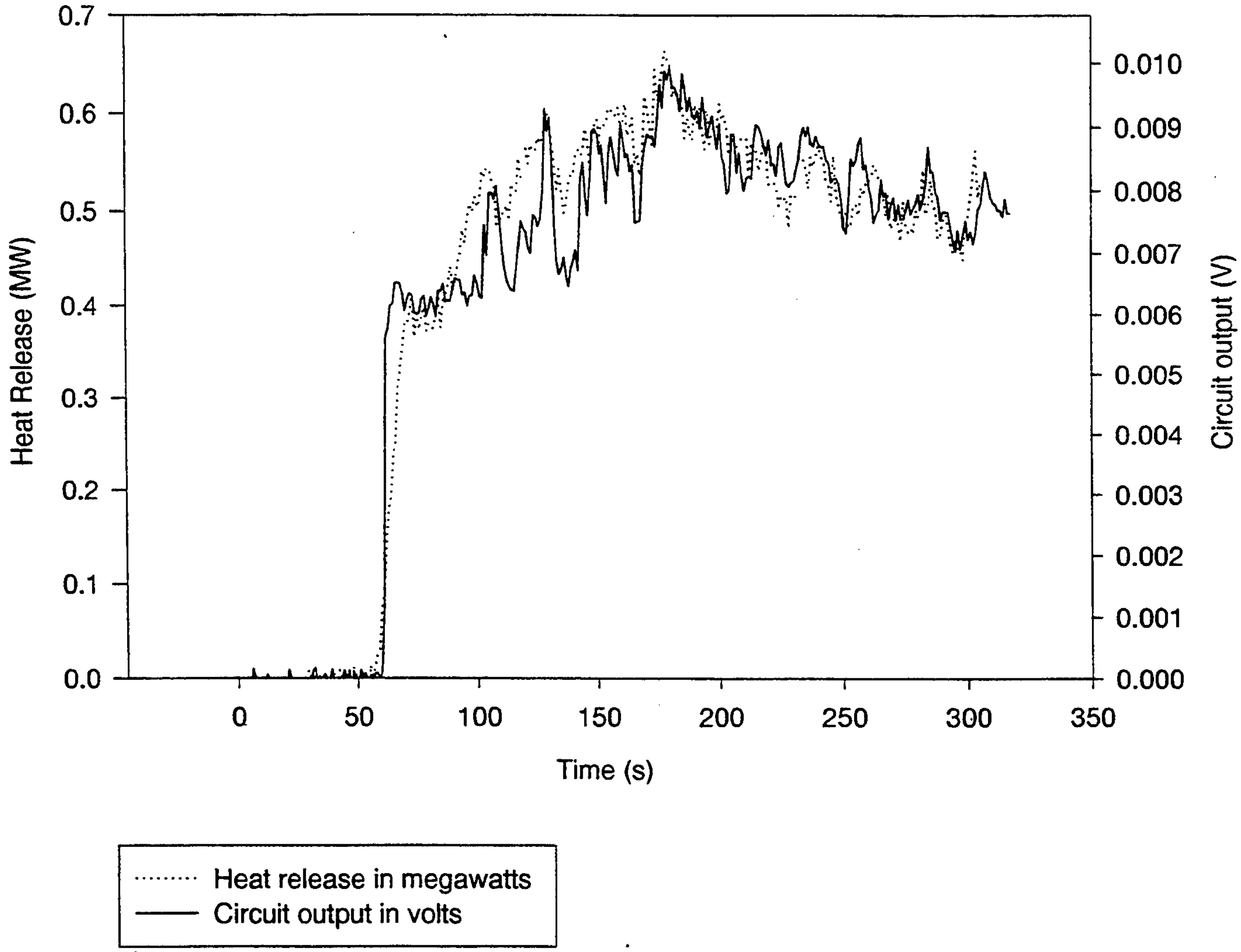


Figure 4. Comparison of heat release from a 0.6 m x 0.6 m square pan and Ni-chrome wire circuit output.

Appendix C

Optical Fire Detector Response Results

This appendix contains the optical fire detector results for all fire tests conducted. The appendix is arranged per the 21 test scenarios conducted, as listed in Table 5 of the report. Each section contains two types of tables, one presenting OFD alarm times and the second presenting the heat release rate (HRR) at the time of alarm for each OFD.

Appendix C Contents

Scenario 1

Fuel Flow Rate: .42 Lpm
Scenario: Unconfined
Fuel: JP-8

Time to Alarm from Ignition (s)								
Test	Ofd003	Ofd004	Ofd076	Ofd077	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	31	33	34	26	4/4	31	3.6	11.5%
OFD2A					0/4			
OFD3A	25	28	27	21	4/4	25	3.1	12.3%
OFD4A	70	65	48	38	4/4	55	14.9	26.9%
OFD5A					0/4			
OFD6A	24	30	22	20	4/4	24	4.3	18.0%
OFD1B	33	38	32	36	4/4	35	2.8	7.9%
OFD2B					0/4			
OFD3B	29	39		32	4/4	33	5.1	15.4%
OFD4B				70	1/4			
OFD5B					0/4			
OFD6B	27	30	22	25	4/4	26	3.4	12.9%
OFD1C	28	38	36	34	4/4	34	4.3	12.7%
OFD2C					0/4			
OFD3C	29	39	32	32	4/4	33	4.2	12.9%
OFD4C	81		73	69	3/4	74	6.1	8.2%
OFD5C					0/4			
OFD6C	24	26	29	25	4/4	26	2.2	8.3%
OFD1D	34	38		32	3/4	35	3.1	8.8%
OFD2D					0/4			
OFD3D	28	37	32	30	4/4	32	3.9	12.2%
OFD4D				84	1/4			
OFD5D					0/4			
OFD6D	30	30	29	28	4/4	29	1.0	3.3%
OFD1E		126		73	2/4	100	37.5	37.7%
OFD2E					0/4			
OFD3E				71	2/4			
OFD4E					0/4			
OFD5E					0/4			
OFD6E	30	33	35	34	4/4	33	2.2	6.5%
OFD1F		90		73	2/4	82	12.0	14.7%
OFD2F					0/4			
OFD3F				73	2/4			
OFD4F					1/4			
OFD5F					0/4			
OFD6F	30	33	29	25	4/4	29	3.3	11.3%

Scenario 1

Fuel Flow Rate: .85 Lpm
Scenario:Unconfined
Fuel: JP-8

Time to Alarm from Ignition (s)								
Test	Ofd005	Ofd006	Ofd078	Ofd079	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	24	19	21	26	4/4	23	3.1	13.8%
OFD2A					0/4			
OFD3A	23	19	20	21	4/4	21	1.7	8.2%
OFD4A	37	32	34	34	4/4	34	2.1	6.0%
OFD5A	42	84	61	52	4/4	60	17.9	30.0%
OFD6A	21	19	20	22	4/4	21	1.3	6.3%
OFD1B	28	22	25	29	4/4	26	3.2	12.2%
OFD2B					0/4			
OFD3B	26	21	22	27	4/4	24	2.9	12.3%
OFD4B	40	33	34	44	4/4	38	5.2	13.7%
OFD5B					0/4			
OFD6B	21	19	20	24	4/4	21	2.2	10.3%
OFD1C	26	22	25	28	4/4	25	2.5	9.9%
OFD2C					0/4			
OFD3C	26	22	22	28	4/4	25	3.0	12.2%
OFD4C	39	33	38	45	4/4	39	4.9	12.7%
OFD5C					0/4			
OFD6C	21	19	20	21	4/4	20	1.0	4.7%
OFD1D	26	22	28	35	4/4	28	5.4	19.6%
OFD2D					0/4			
OFD3D	26	22	22	25	4/4	24	2.1	8.7%
OFD4D	57	51	38	49	4/4	49	7.9	16.3%
OFD5D					0/4			
OFD6D	27	24	22	23	4/4	24	2.2	9.0%
OFD1E	60	59	48	63	4/4	58	6.6	11.4%
OFD2E					0/4			
OFD3E	39	35	37	45	4/4	39	4.3	11.1%
OFD4E	87			93	2/4	90	4.2	4.7%
OFD5E					0/4			
OFD6E	27	24	22	29	4/4	26	3.1	12.2%
OFD1F	53	58	47	42	4/4	50	7.0	14.0%
OFD2F					0/4			
OFD3F	39	35	37	47	4/4	40	5.3	13.3%
OFD4F	87	89		52	3/4	76	20.8	27.4%
OFD5F					0/4			
OFD6F	27	21	25	26	4/4	25	2.6	10.6%

Scenario 1

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined
Fuel: JP-8

Time to Alarm from Ignition (s)								
Test	Ofd007	Ofd008	Ofd084	Ofd085	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	29	32	28	22	4/4	28	4.2	15.1%
OFD2A	51	49		70	4/4	57	11.6	20.5%
OFD3A	26	28	28	20	4/4	26	3.8	14.8%
OFD4A	51	58	48	29	4/4	47	12.4	26.7%
OFD5A	42	44	74	36	4/4	49	17.0	34.7%
OFD6A	23	27	27	24	4/4	25	2.1	8.2%
OFD1B	31	34	32	21	4/4	30	5.8	19.7%
OFD2B					0/4			
OFD3B	28	32	37	22	4/4	30	6.3	21.3%
OFD4B	55	73	52	30	4/4	53	17.6	33.6%
OFD5B					0/4			
OFD6B	23	27	27	22	4/4	25	2.6	10.6%
OFD1C	29	32	36	22	4/4	30	5.9	19.9%
OFD2C					0/4			
OFD3C	28	31	37	22	4/4	30	6.2	21.2%
OFD4C	49	56	51	31	4/4	47	10.9	23.3%
OFD5C					0/4			
OFD6C	23	30	27	22	4/4	26	3.7	14.5%
OFD1D	35	35	35	29	4/4	34	3.0	9.0%
OFD2D					0/4			
OFD3D	28	30	37	22	4/4	29	6.2	21.1%
OFD4D	55	80	69	34	4/4	60	19.8	33.3%
OFD5D					0/4			
OFD6D	28	35	30	25	4/4	30	4.2	14.2%
OFD1E	47	52	55	61	4/4	54	5.9	10.9%
OFD2E					0/4			
OFD3E	40	43	54	32	4/4	42	9.1	21.6%
OFD4E	56	56		57	3/4	56	0.6	1.0%
OFD5E					0/4			
OFD6E	31	35	33	22	4/4	30	5.7	19.0%
OFD1F	44	51	52	48	4/4	49	3.6	7.4%
OFD2F					0/4			
OFD3F	38			92	3/4	65	38.2	58.7%
OFD4F	57	56	69	37	4/4	55	13.2	24.2%
OFD5F					0/4			
OFD6F	28	32	38	29	4/4	32	4.5	14.2%

Scenario 1

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined Spill
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)								
Test	Ofd001	Ofd002	Ofd073	Ofd074	Ofd075	Avg.	Std. Dev.	Variance
OFD1A	0.07	0.08	0.07	0.09	0.11	0.08	0.02	19.9%
OFD2A								
OFD3A	0.05	0.05	0.03	0.06	0.05	0.05	0.01	22.8%
OFD4A								
OFD5A								
OFD6A	0.02	0.04	0.03	0.04	0.03	0.03	0.01	26.1%
OFD1B				0.08	0.11	0.10	0.02	22.3%
OFD2B								
OFD3B	0.05	0.09	0.06	0.09	0.08	0.07	0.02	24.5%
OFD4B								
OFD5B								
OFD6B	0.02	0.04	0.03	0.04	0.05	0.04	0.01	31.7%
OFD1C	0.06	0.09		0.1		0.08	0.02	25.0%
OFD2C								
OFD3C	0.06	0.09	0.07	0.09	0.08	0.08	0.01	16.7%
OFD4C								
OFD5C								
OFD6C	0.02	0.06	0.03	0.04	0.02	0.03	0.02	49.2%
OFD1D								
OFD2D								
OFD3D	0.05	0.09	0.06	0.08	0.06	0.07	0.02	24.2%
OFD4D								
OFD5D								
OFD6D	0.04	0.06	0.04	0.05	0.06	0.05	0.01	20.0%
OFD1E								
OFD2E								
OFD3E								
OFD4E								
OFD5E								
OFD6E	0.04	0.05	0.05	0.07	0.06	0.05	0.01	21.1%
OFD1F								
OFD2F								
OFD3F								
OFD4F								
OFD5F								
OFD6F	0.04	0.07	0.05	0.07	0.07	0.06	0.01	24%

Scenario 1

Fuel Flow Rate: .42 Lpm
Scenario: Unconfined
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)							
Test	Ofd003	Ofd004	Ofd076	Ofd077	Avg.	Std. Dev.	Variance
OFD1A	0.10	0.09	0.10	0.09	0.10	0.01	6.1%
OFD2A							
OFD3A	0.07	0.06	0.09	0.06	0.07	0.01	20.2%
OFD4A	0.22	0.20	0.17	0.15	0.19	0.03	16.8%
OFD5A							
OFD6A	0.06	0.07	0.06	0.06	0.06	0.00	8.0%
OFD1B	0.12	0.13	0.10	0.14	0.12	0.02	13.9%
OFD2B							
OFD3B	0.09	0.13		0.12	0.11	0.02	18.4%
OFD4B				0.27			
OFD5B							
OFD6B	0.08	0.07	0.06	0.08	0.07	0.01	13.2%
OFD1C	0.09	0.13	0.13	0.13	0.12	0.02	16.7%
OFD2C							
OFD3C	0.09	0.13	0.10	0.12	0.11	0.02	16.6%
OFD4C	0.23		0.25	0.28	0.25	0.03	9.9%
OFD5C							
OFD6C	0.06	0.05	0.10	0.08	0.07	0.02	30.6%
OFD1D	0.12	0.13		0.12	0.12	0.01	4.7%
OFD2D							
OFD3D	0.09	0.12	0.10	0.11	0.11	0.01	12.3%
OFD4D				0.26			
OFD5D							
OFD6D	0.10	0.07	0.10	0.10	0.09	0.02	16.2%
OFD1E		0.29		0.26	0.28	0.02	7.7%
OFD2E							
OFD3E				0.28			
OFD4E							
OFD5E							
OFD6E	0.10	0.09	0.12	0.13	0.11	0.02	16.6%
OFD1F		0.27		0.26	0.27	0.01	2.7%
OFD2F							
OFD3F				0.26			
OFD4F							
OFD5F							
OFD6F	0.10	0.09	0.10	0.08	0.09	0.01	10.4%

Scenario 1

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)							
Test	Ofd007	Ofd008	Ofd084	Ofd085	Avg.	Std. Dev.	Variance
OFD1A	0.17	0.17	0.07	0.15	0.14	0.05	34.0%
OFD2A	0.67	0.67		0.91	0.75	0.14	18.5%
OFD3A	0.12	0.1	0.07	0.11	0.10	0.02	21.6%
OFD4A	0.67	0.83	0.37	0.3	0.54	0.25	46.1%
OFD5A	0.52	0.52	0.86	0.42	0.58	0.19	33.2%
OFD6A	0.08	0.1	0.05	0.2	0.11	0.07	60.5%
OFD1B	0.21	0.22	0.11	0.13	0.17	0.06	33.2%
OFD2B							
OFD3B	0.15	0.15	0.18	0.15	0.16	0.01	9.5%
OFD4B	0.65	0.8	0.44	0.24	0.53	0.24	45.9%
OFD5B							
OFD6B	0.08	0.14	0.05	0.15	0.11	0.05	45.7%
OFD1C	0.17	0.17	0.1	0.15	0.15	0.03	22.4%
OFD2C							
OFD3C	0.15	0.15	0.18	0.15	0.16	0.01	9.5%
OFD4C	0.65	0.8	0.44	0.24	0.53	0.24	45.9%
OFD5C							
OFD6C	0.08	0.14	0.05	0.15	0.11	0.05	45.7%
OFD1D	0.32	0.25	0.15	0.3	0.26	0.08	29.8%
OFD2D							
OFD3D	0.15	0.14	0.18	0.15	0.16	0.02	11.2%
OFD4D	0.72	0.89	0.81	0.39	0.70	0.22	31.3%
OFD5D							
OFD6D	0.15	0.25	0.09	0.2	0.17	0.07	39.7%
OFD1E	0.62	0.74	0.53	0.85	0.69	0.14	20.4%
OFD2E							
OFD3E	0.47	0.5	0.51	0.35	0.46	0.07	16.1%
OFD4E	0.72	0.8		0.8	0.77	0.05	6.0%
OFD5E							
OFD6E	0.21	0.25	0.12	0.15	0.18	0.06	32.1%
OFD1F	0.56	0.72	0.46	0.66	0.60	0.11	19.1%
OFD2F							
OFD3F	0.41			0.31	0.36	0.07	19.6%
OFD4F	0.73	0.8	0.81	0.44	0.70	0.17	25.0%
OFD5F							
OFD6F	0.15	0.17	0.2	0.3	0.21	0.07	32.5%

Scenario 1

Fuel Flow Rate: .85 Lpm
Scenario:Unconfined
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)							
Test	Ofd005	Ofd006	Ofd078	Ofd079	Avg.	Std. Dev.	Variance
OFD1A	0.12	0.11	0.09	0.15	0.12	0.03	21.3%
OFD2A							
OFD3A	0.10	0.11	0.08	0.11	0.10	0.01	14.1%
OFD4A	0.27	0.25	0.21	0.24	0.24	0.03	10.3%
OFD5A	0.32	0.45	0.44	0.48	0.42	0.07	16.7%
OFD6A	0.07	0.11	0.08	0.11	0.09	0.02	22.3%
OFD1B	0.17	0.14	0.13	0.18	0.16	0.02	15.4%
OFD2B							
OFD3B	0.15	0.13	0.10	0.16	0.14	0.03	19.6%
OFD4B	0.30	0.26	0.21	0.38	0.29	0.07	25.0%
OFD5B							
OFD6B	0.07	0.11	0.08	0.11	0.09	0.02	22.3%
OFD1C	0.15	0.14	0.13	0.17	0.15	0.02	11.6%
OFD2C							
OFD3C	0.15	0.14	0.10	0.17	0.14	0.03	21.0%
OFD4C	0.29	0.26	0.26	0.40	0.30	0.07	22.0%
OFD5C							
OFD6C	0.07	0.11	0.08	0.11	0.09	0.02	22.3%
OFD1D	0.15	0.14	0.14	0.26	0.17	0.06	33.9%
OFD2D							
OFD3D	0.15	0.14	0.10	0.12	0.13	0.02	17.4%
OFD4D	0.42	0.41	0.26	0.45	0.39	0.09	22.1%
OFD5D							
OFD6D	0.16	0.16	0.10	0.10	0.13	0.03	26.6%
OFD1E	0.43	0.46	0.39	0.52	0.45	0.05	12.2%
OFD2E							
OFD3E	0.29	0.28	0.25	0.40	0.31	0.07	21.5%
OFD4E	0.44						
OFD5E							
OFD6E	0.16	0.16	0.10	0.19	0.15	0.04	24.8%
OFD1F	0.40	0.45	0.38	0.35	0.40	0.04	10.6%
OFD2F							
OFD3F	0.29	0.28	0.25	0.42	0.31	0.08	24.3%
OFD4F	0.44	0.51		0.48	0.48	0.04	7.4%
OFD5F							
OFD6F	0.16	0.13	0.13	0.15	0.14	0.01	10.5%

Scenario 2

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined w/ mod. UV/IR
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd066	Ofd067	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A			0/2			
OFD2A			0/2			
OFD3A	14	16	2/2	15	1.4	9.4%
OFD4A			0/2			
OFD5A			0/2			
OFD6A	17	15	2/2	16	1.4	8.8%
OFD1B			0/2			
OFD2B			0/2			
OFD3B	68	58	2/2	63	7.1	11.2%
OFD4B			0/2			
OFD5B			0/2			
OFD6B	19	21	2/2	20	1.4	7.1%
OFD1C			0/2			
OFD2C			0/2			
OFD3C	28	29	2/2	29	0.7	2.5%
OFD4C			0/2			
OFD5C			0/2			
OFD6C	19	21	2/2	20	1.4	7.1%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	27	23	2/2	25	2.8	11.3%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	27	21	2/2	24	4.2	17.7%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	27	21	2/2	24	4.2	17.7%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	27	32	2/2	30	3.5	12.0%

Scenario 2

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ mod.UV/IR
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd050	Ofd051	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	27	25	2/2	26	1.4	5.4%
OFD2A			0/2			
OFD3A	16	16	2/2	16	0.0	0.0%
OFD4A	40	48	2/2	44	5.7	12.9%
OFD5A	41	55	2/2	48	9.9	20.6%
OFD6A	22	23	2/2	23	0.7	3.1%
OFD1B	30	28	2/2	29	1.4	4.9%
OFD2B			0/2			
OFD3B	26	26	2/2	26	0.0	0.0%
OFD4B	41	52	2/2	47	7.8	16.7%
OFD5B			0/2			
OFD6B	22	29	2/2	26	4.9	19.4%
OFD1C	30	30	2/2	30	0.0	0.0%
OFD2C			0/2			
OFD3C	26	24	2/2	25	1.4	5.7%
OFD4C	41	50	2/2	46	6.4	14.0%
OFD5C			0/2			
OFD6C	22	23	2/2	23	0.7	3.1%
OFD1D	33	32	2/2	33	0.7	2.2%
OFD2D			0/2			
OFD3D	26	25	2/2	26	0.7	2.8%
OFD4D	36	43	2/2	40	4.9	12.5%
OFD5D			0/2			
OFD6D	29	25	2/2	27	2.8	10.5%
OFD1E	34	33	2/2	34	0.7	2.1%
OFD2E			0/2			
OFD3E	40	42	2/2	41	1.4	3.4%
OFD4E	46	54	2/2	50	5.7	11.3%
OFD5E			0/2			
OFD6E	31	25	2/2	28	4.2	15.2%
OFD1F	53		1/2			
OFD2F			0/2			
OFD3F	40		1/2			
OFD4F	46	53	2/2	50	4.9	10.0%
OFD5F			0/2			
OFD6F	31	31	2/2	31	0.0	0.0%

Scenario 2

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined w/ mod. UV/IR
Fuel: JP-8

Heat Release Rate at Time of Alarm (MW)					
Test	Ofd066	Ofd067	Avg.	Std. Dev.	Variance
OFD1A					
OFD2A					
OFD3A	0.05	0.08	0.07	0.02	32.6%
OFD4A					
OFD5A					
OFD6A	0.08	0.06	0.07	0.01	20.2%
OFD1B					
OFD2B					
OFD3B	0.85	0.89	0.87	0.03	3.3%
OFD4B					
OFD5B					
OFD6B	0.11	0.16	0.14	0.04	26.2%
OFD1C					
OFD2C					
OFD3C	0.33	0.35	0.34	0.01	4.2%
OFD4C					
OFD5C					
OFD6C	0.11	0.16	0.14	0.04	26.2%
OFD1D					
OFD2D					
OFD3D	0.30	0.20	0.25	0.07	28.3%
OFD4D					
OFD5D					
OFD6D	0.30	0.16	0.23	0.10	43.0%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.30	0.16	0.23	0.10	43.0%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.30	0.44	0.37	0.10	26.8%

Scenario 2

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ mod.UV/IR
Fuel: JP-8

Heat Release Rate at Time of Alarm (MW)					
Test	Ofd050	Ofd051	Avg.	Std. Dev.	Variance
OFD1A	0.07	0.06	0.07	0.01	10.9%
OFD2A					
OFD3A	0.04	0.05	0.05	0.01	15.7%
OFD4A	0.09	0.09	0.09	0.00	0.0%
OFD5A	0.09	0.10	0.10	0.01	7.4%
OFD6A	0.06	0.06	0.06	0.00	0.0%
OFD1B	0.08	0.07	0.08	0.01	9.4%
OFD2B					
OFD3B	0.07	0.07	0.07	0.00	0.0%
OFD4B	0.09	0.09	0.09	0.00	0.0%
OFD5B					
OFD6B	0.06	0.07	0.07	0.01	10.9%
OFD1C	0.08	0.07	0.08	0.01	9.4%
OFD2C					
OFD3C	0.07	0.06	0.07	0.01	10.9%
OFD4C	0.09	0.09	0.09	0.00	0.0%
OFD5C					
OFD6C	0.06	0.06	0.06	0.00	0.0%
OFD1D	0.08	0.07	0.08	0.01	9.4%
OFD2D					
OFD3D	0.07	0.06	0.07	0.01	10.9%
OFD4D	0.09	0.09	0.09	0.00	0.0%
OFD5D					
OFD6D	0.07	0.06	0.07	0.01	10.9%
OFD1E	0.08	0.08	0.08	0.00	0.0%
OFD2E					
OFD3E	0.09	0.09	0.09	0.00	0.0%
OFD4E	0.10	0.10	0.10	0.00	0.0%
OFD5E					
OFD6E	0.08	0.06	0.07	0.01	20.2%
OFD1F	0.11				
OFD2F					
OFD3F	0.09				
OFD4F	0.10	0.09	0.10	0.01	7.4%
OFD5F					
OFD6F	0.08	0.07	0.08	0.01	9.4%

Scenario 3

Fuel Flow Rate: .17 Lpm
Scenario:Unconfined w/ chopped IR at 20m
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd068	Ofd069	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	30	23	2/2	27	4.9	18.7%
OFD2A			0/2			
OFD3A	50	36	2/2	43	9.9	23.0%
OFD4A			0/2			
OFD5A			0/2			
OFD6A	24	25	2/2	25	0.7	2.9%
OFD1B		29	1/2			
OFD2B			0/2			
OFD3B			0/2			
OFD4B			0/2			
OFD5B			0/2			
OFD6B	24	25	2/2	25	0.7	2.9%
OFD1C	56	21	2/2	39	24.7	64.3%
OFD2C			0/2			
OFD3C			0/2			
OFD4C			0/2			
OFD5C			0/2			
OFD6C	24	25	2/2	25	0.7	2.9%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	26	18	2/2	22	5.7	25.7%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	26	23	2/2	25	2.1	8.7%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	44	23	2/2	34	14.8	44.3%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	26	23	2/2	25	2.1	8.7%

Scenario 3

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ chopped IR at 20 m
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd046	Ofd047	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	27	25	2/2	26	1.4	5.4%
OFD2A			0/2			
OFD3A	32	33	2/2	33	0.7	2.2%
OFD4A	77	82	2/2	80	3.5	4.4%
OFD5A	42	49	2/2	46	4.9	10.9%
OFD6A	13	33	2/2	23	14.1	61.5%
OFD1B	25	28	2/2	27	2.1	8.0%
OFD2B			0/2			
OFD3B	52	55	2/2	54	2.1	4.0%
OFD4B			0/2			
OFD5B			0/2			
OFD6B	25	39	2/2	32	9.9	30.9%
OFD1C	31	28	2/2	30	2.1	7.2%
OFD2C			0/2			
OFD3C	50	59	2/2	55	6.4	11.7%
OFD4C			0/2			
OFD5C			0/2			
OFD6C	27	36	2/2	32	6.4	20.2%
OFD1D	26	30	2/2	28	2.8	10.1%
OFD2D			0/2			
OFD3D	23	22	2/2	23	0.7	3.1%
OFD4D	55	57	2/2	56	1.4	2.5%
OFD5D			0/2			
OFD6D	29	30	2/2	30	0.7	2.4%
OFD1E	45	46	2/2	46	0.7	1.6%
OFD2E			0/2			
OFD3E	49	54	2/2	52	3.5	6.9%
OFD4E	60	60	2/2	60	0.0	0.0%
OFD5E			0/2			
OFD6E	38	41	2/2	40	2.1	5.4%
OFD1F	53	39	2/2	46	9.9	21.5%
OFD2F			0/2			
OFD3F			0/2			
OFD4F	60	60	2/2	60	0.0	0.0%
OFD5F			0/2			
OFD6F	32	38	2/2	35	4.2	12.1%

Scenario 3

Fuel Flow Rate: .17 Lpm
Scenario:Unconfined w/ chopped IR at 20m
Fuel: JP-8

Heat Release Rate at Time of Alarm (MW)					
Test	Ofd068	Ofd069	Avg.	Std. Dev.	Variance
OFD1A	0.08	0.06	0.07	0.01	20.2%
OFD2A					
OFD3A	0.09	0.09	0.09	0.00	0.0%
OFD4A					
OFD5A					
OFD6A	0.07	0.07	0.07	0.00	0.0%
OFD1B		0.09			
OFD2B					
OFD3B					
OFD4B					
OFD5B					
OFD6B	0.07	0.07	0.07	0.00	0.0%
OFD1C	0.11	0.06	0.09	0.04	41.6%
OFD2C					
OFD3C					
OFD4C					
OFD5C					
OFD6C	0.07	0.07	0.07	0.00	0.0%
OFD1D					
OFD2D					
OFD3D	0.07	0.04	0.06	0.02	38.6%
OFD4D					
OFD5D					
OFD6D	0.07	0.06	0.07	0.01	10.9%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.08	0.06	0.07	0.01	20.2%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.07	0.06	0.07	0.01	10.9%

Scenario 3

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ chopped IR at 20 m
Fuel: JP-8

Heat Release Rate at Time of Alarm (MW)					
Test	Ofd046	Ofd047	Avg.	Std. Dev.	Variance
OFD1A	0.20	0.13	0.17	0.05	30.0%
OFD2A					
OFD3A	0.31	0.29	0.30	0.01	4.7%
OFD4A	0.83	0.76	0.80	0.05	6.2%
OFD5A	0.52	0.69	0.61	0.12	19.9%
OFD6A	0.03	0.29	0.16	0.18	114.9%
OFD1B	0.17	0.18	0.18	0.01	4.0%
OFD2B					
OFD3B	0.69	0.76	0.73	0.05	6.8%
OFD4B					
OFD5B					
OFD6B	0.17	0.44	0.31	0.19	62.6%
OFD1C	0.28	0.18	0.23	0.07	30.7%
OFD2C					
OFD3C	0.67	0.78	0.73	0.08	10.7%
OFD4C					
OFD5C					
OFD6C	0.20	0.37	0.29	0.12	42.2%
OFD1D	0.18	0.22	0.20	0.03	14.1%
OFD2D					
OFD3D	0.13	0.12	0.13	0.01	5.7%
OFD4D	0.71	0.77	0.74	0.04	5.7%
OFD5D					
OFD6D	0.24	0.22	0.23	0.01	6.1%
OFD1E	0.58	0.62	0.60	0.03	4.7%
OFD2E					
OFD3E	0.65	0.75	0.70	0.07	10.1%
OFD4E	0.73	0.79	0.76	0.04	5.6%
OFD5E					
OFD6E	0.44	0.49	0.47	0.04	7.6%
OFD1F	0.69	0.44	0.57	0.18	31.3%
OFD2F					
OFD3F					
OFD4F	0.73	0.79	0.76	0.04	5.6%
OFD5F					
OFD6F	0.31	0.42	0.37	0.08	21.3%

Scenario 4

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined w/ chopped IR at 26m
Fuel: JP-8

Time to Alarm from Ignition (s)							
Test	Ofd070	Ofd071	Ofd072	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	21	*N/A	39	2/3	30	12.7	42.4%
OFD2A		*N/A		0/3			
OFD3A		*N/A		0/3			
OFD4A		*N/A		0/3			
OFD5A		*N/A		0/3			
OFD6A	27	*N/A	37	2/3	32	7.1	22.1%
OFD1B		*N/A		0/3			
OFD2B		*N/A		0/3			
OFD3B		*N/A		0/3			
OFD4B		*N/A		0/3			
OFD5B		*N/A		0/3			
OFD6B	30	*N/A	34	2/3	32	2.8	8.8%
OFD1C	26	*N/A	51	2/3	39	17.7	45.9%
OFD2C		*N/A		0/3			
OFD3C		*N/A		0/3			
OFD4C		*N/A		0/3			
OFD5C	34	*N/A	25	2/3	30	6.4	21.6%
OFD6C	39	*N/A	36	2/3	38	2.1	5.7%
OFD1D				0/3			
OFD2D				0/3			
OFD3D	20	35	25	3/3	27	7.6	28.6%
OFD4D				0/3			
OFD5D				0/3			
OFD6D	24	20	23	3/3	22	2.1	9.3%
OFD1E				0/3			
OFD2E				0/3			
OFD3E				0/3			
OFD4E				0/3			
OFD5E				0/3			
OFD6E	21	27	23	3/3	24	3.1	12.9%
OFD1F				0/3			
OFD2F				0/3			
OFD3F				0/3			
OFD4F				0/3			
OFD5F				0/3			
OFD6F	27	47	23	3/3	32	12.9	39.8%

* Power Supply not on

Scenario 4

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ chopped IR at 26 m
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd048	Ofd049	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	24	25	2/2	25	0.7	2.8%
OFD2A			0/2			
OFD3A	32	38	2/2	35	4.2	12.1%
OFD4A			0/2			
OFD5A	51	46	2/2	49	3.5	7.3%
OFD6A	25	29	2/2	27	2.8	10.5%
OFD1B	27	27	2/2	27	0.0	0.0%
OFD2B	77		1/2			
OFD3B	63		1/2			
OFD4B			0/2			
OFD5B			0/2			
OFD6B	40	32	2/2	36	5.7	15.7%
OFD1C	24	28	2/2	26	2.8	10.9%
OFD2C			0/2			
OFD3C			0/2			
OFD4C			0/2			
OFD5C	27	31	2/2	29	2.8	9.8%
OFD6C	35	32	2/2	34	2.1	6.3%
OFD1D	28	30	2/2	29	1.4	4.9%
OFD2D			0/2			
OFD3D	24	26	2/2	25	1.4	5.7%
OFD4D	82	84	2/2	83	1.4	1.7%
OFD5D			0/2			
OFD6D	26	28	2/2	27	1.4	5.2%
OFD1E		57	1/2			
OFD2E			0/2			
OFD3E	39	47	2/2	43	5.7	13.2%
OFD4E	82	62	2/2	72	14.1	19.6%
OFD5E			0/2			
OFD6E	26	31	2/2	29	3.5	12.4%
OFD1F	53		1/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	29	28	2/2	29	0.7	2.5%

Scenario 4

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined w/ chopped IR at 26m
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)						
Test	Ofd070	Ofd071	Ofd072	Avg.	Std. Dev.	Variance
OFD1A	0.06	*N/A	0.07	0.07	0.01	10.9%
OFD2A		*N/A				
OFD3A		*N/A				
OFD4A		*N/A				
OFD5A		*N/A				
OFD6A	0.08	*N/A	0.06	0.07	0.01	20.2%
OFD1B		*N/A				
OFD2B		*N/A				
OFD3B		*N/A				
OFD4B		*N/A				
OFD5B		*N/A				
OFD6B	0.08	*N/A	0.06	0.07	0.01	20.2%
OFD1C	0.07	*N/A	0.08	0.08	0.01	9.4%
OFD2C		*N/A				
OFD3C		*N/A				
OFD4C		*N/A				
OFD5C	0.08	*N/A	0.06	0.07	0.01	20.2%
OFD6C	0.08	*N/A	0.06	0.07	0.01	20.2%
OFD1D						
OFD2D						
OFD3D	0.05	0.08	0.06	0.06	0.02	24.1%
OFD4D						
OFD5D						
OFD6D	0.07	0.06	0.06	0.06	0.01	9.1%
OFD1E						
OFD2E						
OFD3E						
OFD4E						
OFD5E						
OFD6E	..06	0.07	0.06	0.07	0.01	10.9%
OFD1F						
OFD2F						
OFD3F						
OFD4F						
OFD5F						
OFD6F	0.08	0.09	0.06	0.08	0.02	19.9%

Scenario 4

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ chopped IR at 26 m
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd048	Ofd049	Avg.	Std. Dev.	Variance
OFD1A	0.19	0.19	0.19	0.00	0.0%
OFD2A					
OFD3A	0.39	0.54	0.47	0.11	22.8%
OFD4A					
OFD5A	0.73	0.73	0.73	0.00	0.0%
OFD6A	0.21	0.29	0.25	0.06	22.6%
OFD1B	0.25	0.24	0.25	0.01	2.9%
OFD2B	0.77				
OFD3B	0.79				
OFD4B					
OFD5B					
OFD6B	0.59	0.37	0.48	0.16	32.4%
OFD1C	0.19	0.26	0.23	0.05	22.0%
OFD2C					
OFD3C					
OFD4C					
OFD5C	0.25	0.34	0.30	0.06	21.6%
OFD6C	0.47	0.37	0.42	0.07	16.8%
OFD1D	0.28	0.31	0.30	0.02	7.2%
OFD2D					
OFD3D	0.19	0.21	0.20	0.01	7.1%
OFD4D	0.79	0.77	0.78	0.01	1.8%
OFD5D					
OFD6D	0.23	0.26	0.25	0.02	8.7%
OFD1E		0.81			
OFD2E					
OFD3E	0.57	0.75	0.66	0.13	19.3%
OFD4E	0.79	0.77	0.78	0.01	1.8%
OFD5E					
OFD6E	0.23	0.34	0.29	0.08	27.3%
OFD1F	0.74				
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.31	0.26	0.29	0.04	12.4%

Scenario 5

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ obstruction 0-1.34 m ht
Fuel: JP-8

Time to Alarm from Ignition (s)							
Test	Ofd052	Ofd053	Ofd054	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A				0/3			
OFD2A				0/3			
OFD3A	39	29	24	3/3	34	7.1	20.8%
OFD4A	46	36	34	3/3	41	7.1	17.2%
OFD5A	70			1/3			
OFD6A	41	34	30	3/3	38	4.9	13.2%
OFD1B				0/3			
OFD2B				0/3			
OFD3B	41	33	27	3/3	37	5.7	15.3%
OFD4B	50	41	38	3/3	46	6.4	14.0%
OFD5B				0/3			
OFD6B	40	31	30	3/3	36	6.4	17.9%
OFD1C				0/3			
OFD2C				0/3			
OFD3C	42	33	32	3/3	38	6.4	17.0%
OFD4C	48	41	42	3/3	45	4.9	11.1%
OFD5C				0/3			
OFD6C	40	34	30	3/3	37	4.2	11.5%
OFD1D				0/3			
OFD2D				0/3			
OFD3D	41	32	26	3/3	37	6.4	17.4%
OFD4D	57	45	42	3/3	51	8.5	16.6%
OFD5D				0/3			
OFD6D	45	34	32	3/3	40	7.8	19.7%
OFD1E				0/3			
OFD2E				0/3			
OFD3E	47	38		2/3	43	6.4	15.0%
OFD4E	57	63		2/3	60	4.2	7.1%
OFD5E				0/3			
OFD6E	45	34	32	3/3	40	7.8	19.7%
OFD1F				0/3			
OFD2F				0/3			
OFD3F				0/3			
OFD4F	58	45		3/3	52	9.2	17.8%
OFD5F				0/3			
OFD6F	42	34	28	3/3	38	5.7	14.9%

Scenario 5

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ obstruction 0-1.34 m ht
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)						
Test	Ofd052	Ofd053	Ofd054	Avg.	Std. Dev.	Variance
OFD1A						
OFD2A						
OFD3A	0.45	0.30	0.22	0.38	0.11	28.3%
OFD4A	0.66	0.49	0.43	0.58	0.12	20.9%
OFD5A	1.01					
OFD6A	0.51	0.43	0.34	0.47	0.06	12.0%
OFD1B						
OFD2B						
OFD3B	0.51	0.41	0.28	0.46	0.07	15.4%
OFD4B	0.75	0.61	0.52	0.68	0.10	14.6%
OFD5B						
OFD6B	0.48	0.35	0.34	0.42	0.09	22.2%
OFD1C						
OFD2C						
OFD3C	0.55	0.41	0.39	0.48	0.10	20.6%
OFD4C	0.70	0.61	0.61	0.66	0.06	9.7%
OFD5C						
OFD6C	0.48	0.43	0.34	0.46	0.04	7.8%
OFD1D						
OFD2D						
OFD3D	0.51	0.38	0.26	0.45	0.09	20.7%
OFD4D	0.85	0.69	0.61	0.77	0.11	14.7%
OFD5D						
OFD6D	0.64	0.43	0.39	0.54	0.15	27.8%
OFD1E						
OFD2E						
OFD3E	0.68	0.54		0.61	0.10	16.2%
OFD4E	0.85	0.93		0.89	0.06	6.4%
OFD5E						
OFD6E	0.64	0.43	0.39	0.54	0.15	27.8%
OFD1F						
OFD2F						
OFD3F						
OFD4F	0.89	0.69		0.79	0.14	17.9%
OFD5F						
OFD6F	0.55	0.43	0.30	0.49	0.08	17.3%

Scenario 6

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ moving obstruction 0-1.34 m ht
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd055	Ofd056	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	62	64	2/2	63	1.4	2.2%
OFD2A	67		0/2			
OFD3A	28	29	2/2	29	0.7	2.5%
OFD4A	44	42	2/2	43	1.4	3.3%
OFD5A	61	63	2/2	62	1.4	2.3%
OFD6A	30	31	2/2	31	0.7	2.3%
OFD1B	64	64	2/2	64	0.0	0.0%
OFD2B			0/2			
OFD3B	31	31	2/2	31	0.0	0.0%
OFD4B	40	42	2/2	41	1.4	3.4%
OFD5B			0/2			
OFD6B	30	31	2/2	31	0.7	2.3%
OFD1C	64	64	2/2	64	0.0	0.0%
OFD2C			0/2			
OFD3C	34		1/2			
OFD4C	45	47	2/2	46	1.4	3.1%
OFD5C			0/2			
OFD6C	30	31	2/2	31	0.7	2.3%
OFD1D	61	65	2/2	63	2.8	4.5%
OFD2D			0/2			
OFD3D	31	31	2/2	31	0.0	0.0%
OFD4D	54	46	2/2	50	5.7	11.3%
OFD5D			1/2			
OFD6D	32	35	2/2	34	2.1	6.3%
OFD1E		71	1/2			
OFD2E			0/2			
OFD3E	73	39	2/2	56	24.0	42.9%
OFD4E	53	58	2/2	56	3.5	6.4%
OFD5E			0/2			
OFD6E	34	35	2/2	35	0.7	2.0%
OFD1F	74	68	2/2	71	4.2	6.0%
OFD2F			0/2			
OFD3F			0/2			
OFD4F	55	59	2/2	57	2.8	5.0%
OFD5F			0/2			
OFD6F	34	35	2/2	35	0.7	2.0%

Scenario 6

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ moving obstruction 0-1.34 m ht
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd055	Ofd056	Avg.	Std. Dev.	Variance
OFD1A	0.89	0.97	0.93	0.06	6.1%
OFD2A	0.90				
OFD3A	0.31	0.31	0.31	0.00	0.0%
OFD4A	0.68	0.64	0.66	0.03	4.3%
OFD5A	0.88	0.96	0.92	0.06	6.1%
OFD6A	0.36	0.36	0.36	0.00	0.0%
OFD1B	0.89	0.97	0.93	0.06	6.1%
OFD2B					
OFD3B	0.39	0.36	0.38	0.02	5.7%
OFD4B	0.60	0.64	0.62	0.03	4.6%
OFD5B					
OFD6B	0.36	0.36	0.36	0.00	0.0%
OFD1C	0.89	0.97	0.93	0.06	6.1%
OFD2C					
OFD3C	0.47				
OFD4C	0.70	0.73	0.72	0.02	3.0%
OFD5C					
OFD6C	0.36	0.36	0.36	0.00	0.0%
OFD1D	0.88	0.97	0.93	0.06	6.9%
OFD2D					
OFD3D	0.39	0.36	0.38	0.02	5.7%
OFD4D	0.83	0.72	0.78	0.08	10.0%
OFD5D					
OFD6D	0.41	0.46	0.44	0.04	8.1%
OFD1E		0.98			
OFD2E					
OFD3E	0.93	0.56	0.75	0.26	35.1%
OFD4E	0.81	0.92	0.87	0.08	9.0%
OFD5E					
OFD6E	0.47	0.46	0.47	0.01	1.5%
OFD1F	0.93	0.98	0.96	0.04	3.7%
OFD2F					
OFD3F					
OFD4F	0.84	0.94	0.89	0.07	7.9%
OFD5F					
OFD6F	0.47	0.46	0.47	0.01	1.5%

Scenario 7

Fuel Flow Rate: .42 Lpm
Scenario: Unconfined w/ obstruction .3-2.3 m ht
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd062	Ofd063	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A			0/2			
OFD2A			0/2			
OFD3A			0/2			
OFD4A			0/2			
OFD5A			0/2			
OFD6A	56	77	2/2	67	14.8	22.3%
OFD1B			0/2			
OFD2B			0/2			
OFD3B			0/2			
OFD4B			0/2			
OFD5B			0/2			
OFD6B			0/2			
OFD1C			0/2			
OFD2C			0/2			
OFD3C			0/2			
OFD4C			0/2			
OFD5C			0/2			
OFD6C		29	1/2			
OFD1D			0/2			
OFD2D			0/2			
OFD3D			0/2			
OFD4D			0/2			
OFD5D			0/2			
OFD6D			0/2			
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E			0/2			
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F			0/2			

Scenario 7

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ obstruction .3-2.3 m ht
Fuel: JP-8

Time to Alarm from Ignition (s)							
Test	Ofd057	Ofd058	Ofd059	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	39	28	38	3/3	35	6.1	17.4%
OFD2A				0/3			
OFD3A	38	33	34	3/3	35	2.6	7.6%
OFD4A	52	52	43	3/3	49	5.2	10.6%
OFD5A				0/3			
OFD6A	33	44	40	3/3	39	5.6	14.3%
OFD1B	49	45	48	3/3	47	2.1	4.4%
OFD2B				0/3			
OFD3B	45	38	37	3/3	40	4.4	10.9%
OFD4B	60	54	46	3/3	53	7.0	13.2%
OFD5B				0/3			
OFD6B	44	34	37	3/3	38	5.1	13.4%
OFD1C	42	42	45	3/3	43	1.7	4.0%
OFD2C				0/3			
OFD3C				0/3			
OFD4C	64	54	43	3/3	54	10.5	19.6%
OFD5C				0/3			
OFD6C	44	34	42	3/3	40	5.3	13.2%
OFD1D	45	54	40	3/3	46	7.1	15.3%
OFD2D				0/3			
OFD3D	43	36	35	3/3	38	4.4	11.5%
OFD4D	64	61	53	3/3	59	5.7	9.6%
OFD5D				0/3			
OFD6D	46	39	37	3/3	41	4.7	11.6%
OFD1E				0/3			
OFD2E				0/3			
OFD3E				0/3			
OFD4E			60	1/3			
OFD5E				0/3			
OFD6E	49	41	39	3/3	43	5.3	12.3%
OFD1F				0/3			
OFD2F				0/3			
OFD3F				0/3			
OFD4F			56	1/3	56		
OFD5F				0/3			
OFD6F	49	44	42	3/3	45	3.6	8.0%

Scenario 7

Fuel Flow Rate: .42 Lpm
Scenario: Unconfined w/ obstruction .3-2.3 m ht
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd062	Ofd063	Avg.	Std. Dev.	Variance
OFD1A					
OFD2A					
OFD3A					
OFD4A					
OFD5A					
OFD6A	0.24	0.30	0.27	0.04	15.7%
OFD1B					
OFD2B					
OFD3B					
OFD4B					
OFD5B					
OFD6B					
OFD1C					
OFD2C					
OFD3C					
OFD4C					
OFD5C					
OFD6C		0.12			
OFD1D					
OFD2D					
OFD3D					
OFD4D					
OFD5D					
OFD6D					
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E					
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F					

Scenario 7

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ obstruction .3-2.3 m ht
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)						
Test	Ofd057	Ofd058	Ofd059	Avg.	Std. Dev.	Variance
OFD1A	0.55	0.34	0.62	0.50	0.15	29.0%
OFD2A						
OFD3A	0.52	0.44	0.53	0.50	0.05	9.9%
OFD4A	0.80	0.82	0.72	0.78	0.05	6.8%
OFD5A						
OFD6A	0.38	0.73	0.66	0.59	0.19	31.4%
OFD1B	0.76	0.75	0.80	0.77	0.03	3.4%
OFD2B						
OFD3B	0.70	0.62	0.60	0.64	0.05	8.3%
OFD4B	0.89	0.85	0.77	0.84	0.06	7.3%
OFD5B						
OFD6B	0.68	0.47	0.60	0.58	0.11	18.2%
OFD1C	0.63	0.71	0.75	0.70	0.06	8.8%
OFD2C						
OFD3C						
OFD4C	0.92	0.85	0.72	0.83	0.10	12.2%
OFD5C						
OFD6C	0.68	0.47	0.70	0.62	0.13	20.7%
OFD1D	0.70	0.85	0.66	0.74	0.10	13.6%
OFD2D						
OFD3D	0.66	0.53	0.55	0.58	0.07	12.1%
OFD4D	0.92	0.90	0.87	0.90	0.03	2.8%
OFD5D						
OFD6D	0.72	0.65	0.60	0.66	0.06	9.2%
OFD1E						
OFD2E						
OFD3E						
OFD4E			0.96			
OFD5E						
OFD6E	0.76	0.68	0.64	0.69	0.06	8.8%
OFD1F						
OFD2F						
OFD3F						
OFD4F			0.92			
OFD5F						
OFD6F	0.76	0.73	0.70	0.73	0.03	4.1%

Scenario 8

Fuel Flow Rate: .42 Lpm
Scenario: Unconfined w/ moving obstruction .3-2.3 m ht
Fuel:JP-8

Time to Alarm from Ignition (s)						
Test	Ofd064	Ofd065	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	94	95	2/2	95	0.7	0.7%
OFD2A			0/2			
OFD3A	93	92	2/2	93	0.7	0.8%
OFD4A	95	95	2/2	95	0.0	0.0%
OFD5A			1/2			
OFD6A	42	97	2/2	70	38.9	56.0%
OFD1B	96	97	2/2	97	0.7	0.7%
OFD2B			0/2			
OFD3B	94	93	2/2	94	0.7	0.8%
OFD4B	100		1/2			
OFD5B			0/2			
OFD6B	100	97	2/2	99	2.1	2.2%
OFD1C	96	95	2/2	96	0.7	0.7%
OFD2C			0/2			
OFD3C	94	93	2/2	94	0.7	0.8%
OFD4C	94	94	2/2	94	0.0	0.0%
OFD5C			0/2			
OFD6C	100	97	2/2	99	2.1	2.2%
OFD1D	95	101	2/2	98	4.2	4.3%
OFD2D			0/2			
OFD3D	93	92	2/2	93	0.7	0.8%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	98	99	2/2	99	0.7	0.7%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	98	99	2/2	99	0.7	0.7%
OFD1F			0/2			
OFD2F			0/2			
OFD3F	96		1/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	98	99	2/2	99	0.7	0.7%

Scenario 8

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ moving obstruction .3-2.3 m ht
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd060	Ofd061	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	28	42	2/2	35	9.9	28.3%
OFD2A			0/2			
OFD3A	38	34	2/2	36	2.8	7.9%
OFD4A	53	57	2/2	55	2.8	5.1%
OFD5A	63	63	2/2	63	0.0	0.0%
OFD6A	33	36	2/2	35	2.1	6.1%
OFD1B	50	48	2/2	49	1.4	2.9%
OFD2B			0/2			
OFD3B	42	36	2/2	39	4.2	10.9%
OFD4B	58	50	2/2	54	5.7	10.5%
OFD5B			0/2			
OFD6B	37	39	2/2	38	1.4	3.7%
OFD1C	40	40	2/2	40	0.0	0.0%
OFD2C			0/2			
OFD3C			0/2			
OFD4C	59	48	2/2	54	7.8	14.5%
OFD5C			0/2			
OFD6C	40	36	2/2	38	2.8	7.4%
OFD1D	33	41	2/2	37	5.7	15.3%
OFD2D			0/2			
OFD3D	40	34	2/2	37	4.2	11.5%
OFD4D	62	62	2/2	62	0.0	0.0%
OFD5D			0/2			
OFD6D	44	39	2/2	42	3.5	8.5%
OFD1E	68	71	2/2	70	2.1	3.1%
OFD2E			0/2			
OFD3E		62	1/2			
OFD4E	62	63	2/2	63	0.7	1.1%
OFD5E			0/2			
OFD6E	50	39	2/2	45	7.8	17.5%
OFD1F	63	66	2/2	65	2.1	3.3%
OFD2F			0/2			
OFD3F			0/2			
OFD4F	62	62	2/2	62	0.0	0.0%
OFD5F			0/2			
OFD6F	50	38	2/2	44	8.5	19.3%

Scenario 8

Fuel Flow Rate: .42 Lpm
Scenario: Unconfined w/ moving obstruction .3-2.3 m ht
Fuel:JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd064	Ofd065	Avg.	Std. Dev.	Variance
OFD1A	0.26	0.26	0.26	0.00	0.0%
OFD2A					
OFD3A	0.26	0.27	0.27	0.01	2.7%
OFD4A	0.26	0.26	0.26	0.00	0.0%
OFD5A					
OFD6A	0.22	0.26	0.24	0.03	11.8%
OFD1B	0.25	0.26	0.26	0.01	2.8%
OFD2B					
OFD3B	0.26	0.27	0.27	0.01	2.7%
OFD4B	0.25				
OFD5B					
OFD6B	0.25	0.26	0.26	0.01	2.8%
OFD1C	0.25	0.26	0.26	0.01	2.8%
OFD2C					
OFD3C	0.26	0.27	0.27	0.01	2.7%
OFD4C	0.26	0.26	0.26	0.00	0.0%
OFD5C					
OFD6C	0.25	0.26	0.26	0.01	2.8%
OFD1D	0.26	0.27	0.27	0.01	2.7%
OFD2D					
OFD3D	0.26	0.27	0.27	0.01	2.7%
OFD4D					
OFD5D					
OFD6D	0.25	0.27	0.26	0.01	5.4%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.25	0.27	0.26	0.01	5.4%
OFD1F					
OFD2F					
OFD3F	0.25				
OFD4F					
OFD5F					
OFD6F	0.25	0.27	0.26	0.01	5.4%

Scenario 8

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ moving obstruction .3-2.3 m ht
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd060	Ofd061	Avg.	Std. Dev.	Variance
OFD1A	0.29	0.66	0.48	0.26	55.1%
OFD2A					
OFD3A	0.56	0.48	0.52	0.06	10.9%
OFD4A	0.88	0.86	0.87	0.01	1.6%
OFD5A	0.90	0.91	0.91	0.01	0.8%
OFD6A	0.43	0.53	0.48	0.07	14.7%
OFD1B	0.83	0.75	0.79	0.06	7.2%
OFD2B					
OFD3B	0.66	0.53	0.60	0.09	15.4%
OFD4B	0.91	0.75	0.83	0.11	13.6%
OFD5B					
OFD6B	0.54	0.59	0.57	0.04	6.3%
OFD1C	0.61	0.61	0.61	0.00	0.0%
OFD2C					
OFD3C					
OFD4C	0.91	0.75	0.83	0.11	13.6%
OFD5C					
OFD6C	0.61	0.53	0.57	0.06	9.9%
OFD1D	0.43	0.63	0.53	0.14	26.7%
OFD2D					
OFD3D	0.61	0.48	0.55	0.09	16.9%
OFD4D	0.90	0.90	0.90	0.00	0.0%
OFD5D					
OFD6D	0.70	0.59	0.65	0.08	12.1%
OFD1E	0.92	0.94	0.93	0.01	1.5%
OFD2E					
OFD3E		0.90			
OFD4E	0.90	0.91	0.91	0.01	0.8%
OFD5E					
OFD6E	0.83	0.59	0.71	0.17	23.9%
OFD1F	0.90	0.93	0.92	0.02	2.3%
OFD2F					
OFD3F					
OFD4F	0.90	0.90	0.90	0.00	0.0%
OFD5F					
OFD6F	0.83	0.57	0.70	0.18	26.3%

Scenario 9

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined w/ arc welding at 15 m
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd080	Ofd081	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A			0/2			
OFD2A			0/2			
OFD3A	38	27	2/2	33	7.8	23.9%
OFD4A			0/2			
OFD5A			0/2			
OFD6A	22	18	2/2	20	2.8	14.1%
OFD1B			0/2			
OFD2B			0/2			
OFD3B	44	84	2/2	64	28.3	44.2%
OFD4B			0/2			
OFD5B			0/2			
OFD6B	27	23	2/2	25	2.8	11.3%
OFD1C			0/2			
OFD2C			0/2			
OFD3C	44	84	2/2	64	28.3	44.2%
OFD4C			0/2			
OFD5C			0/2			
OFD6C	27	21	2/2	24	4.2	17.7%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	43	69	2/2	56	18.4	32.8%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	39	33	2/2	36	4.2	11.8%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	39	30	2/2	35	6.4	18.4%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	39	36	2/2	38	2.1	5.7%

Scenario 9

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ arc welding at 15 m
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd086	Ofd087	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	20	24	2/2	22	2.8	12.9%
OFD2A			0/2			
OFD3A	18	17	2/2	18	0.7	4.0%
OFD4A	33	26	2/2	30	4.9	16.8%
OFD5A	43	42	2/2	43	0.7	1.7%
OFD6A	23	19	2/2	21	2.8	13.5%
OFD1B	24	31	2/2	28	4.9	18.0%
OFD2B			0/2			
OFD3B	26	23	2/2	25	2.1	8.7%
OFD4B	34	39	2/2	37	3.5	9.7%
OFD5B			0/2			
OFD6B	20	19	2/2	20	0.7	3.6%
OFD1C	29	30	2/2	30	0.7	2.4%
OFD2C			0/2			
OFD3C	23	22	2/2	23	0.7	3.1%
OFD4C	38	37	2/2	38	0.7	1.9%
OFD5C			0/2			
OFD6C	20	19	2/2	20	0.7	3.6%
OFD1D	27	32	2/2	30	3.5	12.0%
OFD2D			0/2			
OFD3D	23	22	2/2	23	0.7	3.1%
OFD4D	35	46	2/2	41	7.8	19.2%
OFD5D			0/2			
OFD6D	23	22	2/2	23	0.7	3.1%
OFD1E	37	46	2/2	42	6.4	15.3%
OFD2E			0/2			
OFD3E	36	35	2/2	36	0.7	2.0%
OFD4E	61	65	2/2	63	2.8	4.5%
OFD5E			0/2			
OFD6E	26	28	2/2	27	1.4	5.2%
OFD1F	46	41	2/2	44	3.5	8.1%
OFD2F			0/2			
OFD3F		41	1/2			
OFD4F	53	47	2/2	50	4.2	8.5%
OFD5F			0/2			
OFD6F	28	22	2/2	25	4.2	17.0%

Scenario 9

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined w/ arc welding at 15 m
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd080	Ofd081	Avg.	Std. Dev.	Variance
OFD1A					
OFD2A					
OFD3A	0.06	0.05	0.06	0.01	12.9%
OFD4A					
OFD5A					
OFD6A	0.02	0.03	0.03	0.01	28.3%
OFD1B					
OFD2B					
OFD3B	0.07	0.09	0.08	0.01	17.7%
OFD4B					
OFD5B					
OFD6B	0.03	0.04	0.04	0.01	20.2%
OFD1C					
OFD2C					
OFD3C	0.07	0.09	0.08	0.01	17.7%
OFD4C					
OFD5C					
OFD6C	0.03	0.03	0.03	0.00	0.0%
OFD1D					
OFD2D					
OFD3D	0.07	0.09	0.08	0.01	17.7%
OFD4D					
OFD5D					
OFD6D	0.06	0.06	0.06	0.00	0.0%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.06	0.05	0.06	0.01	12.9%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.06	0.06	0.06	0.00	0.0%

Scenario 9

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ arc welding at 15 m
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd086	Ofd087	Avg.	Std. Dev.	Variance
OFD1A	0.11	0.22	0.17	0.08	47.1%
OFD2A					
OFD3A	0.08	0.09	0.09	0.01	8.3%
OFD4A	0.43	0.27	0.35	0.11	32.3%
OFD5A	0.68	0.64	0.66	0.03	4.3%
OFD6A	0.17	0.12	0.15	0.04	24.4%
OFD1B	0.19	0.40	0.30	0.15	50.3%
OFD2B					
OFD3B	0.24	0.20	0.22	0.03	12.9%
OFD4B	0.45	0.59	0.52	0.10	19.0%
OFD5B					
OFD6B	0.11	0.12	0.12	0.01	6.1%
OFD1C	0.32	0.38	0.35	0.04	12.1%
OFD2C					
OFD3C	0.17	0.18	0.18	0.01	4.0%
OFD4C	0.56	0.55	0.56	0.01	1.3%
OFD5C					
OFD6C	0.17	0.18	0.18	0.01	4.0%
OFD1D	0.27	0.42	0.35	0.11	30.7%
OFD2D					
OFD3D	0.17	0.18	0.18	0.01	4.0%
OFD4D	0.48	0.72	0.60	0.17	28.3%
OFD5D					
OFD6D	0.17	0.18	0.18	0.01	4.0%
OFD1E	0.54	0.72	0.63	0.13	20.2%
OFD2E					
OFD3E	0.51	0.50	0.51	0.01	1.4%
OFD4E	0.90	0.93	0.92	0.02	2.3%
OFD5E					
OFD6E	0.24	0.33	0.29	0.06	22.3%
OFD1F	0.75	0.63	0.69	0.08	12.3%
OFD2F					
OFD3F		0.63			
OFD4F	0.88	0.74	0.81	0.10	12.2%
OFD5F					
OFD6F	0.29	0.18	0.24	0.08	33.1%

Scenario 10

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ arc welding at 27 m
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd088	Ofd089	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	25	20	2/2	23	3.5	15.7%
OFD2A			0/2			
OFD3A	20	21	2/2	21	0.7	3.4%
OFD4A	34	29	2/2	32	3.5	11.2%
OFD5A	43	39	2/2	41	2.8	6.9%
OFD6A	14	19	2/2	17	3.5	21.4%
OFD1B	23	19	2/2	21	2.8	13.5%
OFD2B			0/2			
OFD3B	17	26	2/2	22	6.4	29.6%
OFD4B	36	30	2/2	33	4.2	12.9%
OFD5B			0/2			
OFD6B	14	32	2/2	23	12.7	55.3%
OFD1C	23	11	2/2	17	8.5	49.9%
OFD2C			0/2			
OFD3C		27	1/2			
OFD4C	34	38	2/2	36	2.8	7.9%
OFD5C			0/2			
OFD6C	23	32	2/2	28	6.4	23.1%
OFD1D	29	31	2/2	30	1.4	4.7%
OFD2D			0/2			
OFD3D	25	26	2/2	26	0.7	2.8%
OFD4D	39	40	2/2	40	0.7	1.8%
OFD5D			0/2			
OFD6D	28	29	2/2	29	0.7	2.5%
OFD1E	49	42	2/2	46	4.9	10.9%
OFD2E			0/2			
OFD3E	36	37	2/2	37	0.7	1.9%
OFD4E	56	42	2/2	49	9.9	20.2%
OFD5E			0/2			
OFD6E	28	23	2/2	26	3.5	13.9%
OFD1F	39	42	2/2	41	2.1	5.2%
OFD2F			0/2			
OFD3F		32	1/2			
OFD4F	39	42	2/2	41	2.1	5.2%
OFD5F			0/2			
OFD6F	25	23	2/2	24	1.4	5.9%

Scenario 10

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ arc welding at 27 m
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd088	Ofd089	Avg.	Std. Dev.	Variance
OFD1A	0.17	0.14	0.16	0.02	13.7%
OFD2A					
OFD3A	0.09	0.16	0.13	0.05	39.6%
OFD4A	0.40	0.32	0.36	0.06	15.7%
OFD5A	0.59	0.54	0.57	0.04	6.3%
OFD6A	0.03	0.12	0.08	0.06	84.9%
OFD1B	0.14	0.12	0.13	0.01	10.9%
OFD2B					
OFD3B	0.06	0.25	0.16	0.13	86.7%
OFD4B	0.44	0.34	0.39	0.07	18.1%
OFD5B					
OFD6B	0.03	0.38	0.21	0.25	120.7%
OFD1C	0.14	0.03	0.09	0.08	91.5%
OFD2C					
OFD3C		0.27			
OFD4C	0.40	0.52	0.46	0.08	18.4%
OFD5C					
OFD6C	0.14	0.38	0.26	0.17	65.3%
OFD1D	0.26	0.36	0.31	0.07	22.8%
OFD2D					
OFD3D	0.17	0.25	0.21	0.06	26.9%
OFD4D	0.51	0.57	0.54	0.04	7.9%
OFD5D					
OFD6D	0.24	0.32	0.28	0.06	20.2%
OFD1E	0.71	0.60	0.66	0.08	11.9%
OFD2E					
OFD3E	0.44	0.50	0.47	0.04	9.0%
OFD4E	0.80	0.60	0.70	0.14	20.2%
OFD5E					
OFD6E	0.24	0.19	0.22	0.04	16.4%
OFD1F	0.51	0.60	0.56	0.06	11.5%
OFD2F					
OFD3F		0.38			
OFD4F	0.51	0.60	0.56	0.06	11.5%
OFD5F					
OFD6F	0.17	0.19	0.18	0.01	7.9%

Scenario 11

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined w/ doors open and lights on
Fuel: JP-8

Time to Alarm from Igniton (s)						
Test	Ofd082	Ofd083	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	45	54	2/2	50	6.4	12.9%
OFD2A			0/2			
OFD3A	37	31	2/2	34	4.2	12.5%
OFD4A		83	1/2			
OFD5A			0/2			
OFD6A	25	22	2/2	24	2.1	9.0%
OFD1B	61	64	2/2	63	2.1	3.4%
OFD2B			0/2			
OFD3B	39	51	2/2	45	8.5	18.9%
OFD4B			0/2			
OFD5B			0/2			
OFD6B	25	22	2/2	24	2.1	9.0%
OFD1C			0/2			
OFD2C			0/2			
OFD3C	39	52	2/2	46	9.2	20.2%
OFD4C			0/2			
OFD5C			0/2			
OFD6C	25	22	2/2	24	2.1	9.0%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	39	39	2/2	39	0.0	0.0%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	44	28	2/2	36	11.3	31.4%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	41	30	2/2	36	7.8	21.9%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	41	36	2/2	39	3.5	9.2%

Scenario 11

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ doors open and lights on
Fuel: JP-8

Time to Alarm from Igniton (s)						
Test	Ofd090	Ofd091	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	20	22	2/2	21	1.4	6.7%
OFD2A	56	57	2/2	57	0.7	1.3%
OFD3A	18	18	2/2	18	0.0	0.0%
OFD4A	41	27	2/2	34	9.9	29.1%
OFD5A	29	47	2/2	38	12.7	33.5%
OFD6A	18	17	2/2	18	0.7	4.0%
OFD1B	22	22	2/2	22	0.0	0.0%
OFD2B			0/2			
OFD3B	21	23	2/2	22	1.4	6.4%
OFD4B	29	29	2/2	29	0.0	0.0%
OFD5B			0/2			
OFD6B	21	20	2/2	21	0.7	3.4%
OFD1C	22	24	2/2	23	1.4	6.1%
OFD2C			0/2			
OFD3C	21	23	2/2	22	1.4	6.4%
OFD4C	32	30	2/2	31	1.4	4.6%
OFD5C			0/2			
OFD6C	21	20	2/2	21	0.7	3.4%
OFD1D	22	26	2/2	24	2.8	11.8%
OFD2D			0/2			
OFD3D	21	22	2/2	22	0.7	3.3%
OFD4D	60	30	2/2	45	21.2	47.1%
OFD5D			1/2			
OFD6D	21	19	2/2	20	1.4	7.1%
OFD1E	52	40	2/2	46	8.5	18.4%
OFD2E			0/2			
OFD3E	29	28	2/2	29	0.7	2.5%
OFD4E	43	49	2/2	46	4.2	9.2%
OFD5E			0/2			
OFD6E	21	22	2/2	22	0.7	3.3%
OFD1F	43	41	2/2	42	1.4	3.4%
OFD2F			0/2			
OFD3F	28	83	2/2	56	38.9	70.1%
OFD4F	41	49	2/2	45	5.7	12.6%
OFD5F			0/2			
OFD6F	21	22	2/2	22	0.7	3.3%

Scenario 11

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined w/ doors open and lights on
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd082	Ofd083	Avg.	Std. Dev.	Variance
OFD1A	0.07	0.08	0.08	0.01	9.4%
OFD2A					
OFD3A	0.06	0.05	0.06	0.01	12.9%
OFD4A		0.09			
OFD5A					
OFD6A	0.02	0.03	0.03	0.01	28.3%
OFD1B	0.09	0.08	0.09	0.01	8.3%
OFD2B					
OFD3B	0.06	0.07	0.07	0.01	10.9%
OFD4B					
OFD5B					
OFD6B	0.02	0.03	0.03	0.01	28.3%
OFD1C					
OFD2C					
OFD3C	0.06	0.08	0.07	0.01	20.2%
OFD4C					
OFD5C					
OFD6C	0.02	0.03	0.03	0.01	28.3%
OFD1D					
OFD2D					
OFD3D	0.06	0.06	0.06	0.00	0.0%
OFD4D					
OFD5D					
OFD6D	0.07	0.04	0.06	0.02	38.6%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.07	0.04	0.06	0.02	38.6%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.07	0.06	0.07	0.01	10.9%

Scenario 11

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined w/ doors open and lights on
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd090	Ofd091	Avg.	Std. Dev.	Variance
OFD1A	0.14	0.14	0.14	0.00	0.0%
OFD2A	0.82	0.82	0.82	0.00	0.0%
OFD3A	0.11	0.07	0.09	0.03	31.4%
OFD4A	0.58	0.26	0.42	0.23	53.9%
OFD5A	0.32	0.80	0.56	0.34	60.6%
OFD6A	0.11	0.06	0.09	0.04	41.6%
OFD1B	0.17	0.14	0.16	0.02	13.7%
OFD2B					
OFD3B	0.15	0.16	0.16	0.01	4.6%
OFD4B	0.32	0.32	0.32	0.00	0.0%
OFD5B					
OFD6B	0.15	0.10	0.13	0.04	28.3%
OFD1C	0.17	0.18	0.18	0.01	4.0%
OFD2C					
OFD3C	0.15	0.16	0.16	0.01	4.6%
OFD4C	0.39	0.34	0.37	0.04	9.7%
OFD5C					
OFD6C	0.15	0.10	0.13	0.04	28.3%
OFD1D	0.17	0.23	0.20	0.04	21.2%
OFD2D					
OFD3D	0.15	0.14	0.15	0.01	4.9%
OFD4D	0.85	0.34	0.60	0.36	60.6%
OFD5D					
OFD6D	0.15	0.08	0.12	0.05	43.0%
OFD1E	0.77	0.65	0.71	0.08	12.0%
OFD2E					
OFD3E	0.32	0.29	0.31	0.02	7.0%
OFD4E	0.62	0.83	0.73	0.15	20.5%
OFD5E					
OFD6E	0.15	0.14	0.15	0.01	4.9%
OFD1F	0.62	0.67	0.65	0.04	5.5%
OFD2F					
OFD3F	0.30	0.66	0.48	0.25	53.0%
OFD4F	0.58	0.83	0.71	0.18	25.1%
OFD5F					
OFD6F	0.15	0.14	0.15	0.01	4.9%

Scenario 12

Volume of Fuel: 1 L
Scenario:Fixed Quantity
Fuel:JP-8

Time to Alarm from Ignition (s)	
Test	Ofd009
OFD1A	18
OFD2A	
OFD3A	15
OFD4A	27
OFD5A	
OFD6A	15
OFD1B	20
OFD2B	
OFD3B	17
OFD4B	36
OFD5B	
OFD6B	12
OFD1C	20
OFD2C	
OFD3C	18
OFD4C	36
OFD5C	
OFD6C	12
OFD1D	20
OFD2D	
OFD3D	18
OFD4D	
OFD5D	
OFD6D	19
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	18
OFD1F	
OFD2F	
OFD3F	29
OFD4F	
OFD5F	
OFD6F	21

Scenario 12

Volume of Fuel: 2 L
Scenario: Fixed Quantity
Fuel: JP-8

Time to Alarm from Ignition (s)							
Test	Ofd010	Ofd011	Ofd099	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	69	30	15	3/3	38	27.9	73.4%
OFD2A				0/3			
OFD3A	67	20	14	3/3	34	29.0	86.2%
OFD4A	100	45	19	3/3	55	41.4	75.7%
OFD5A				0/3			
OFD6A	34	12	13	3/3	20	12.4	63.2%
OFD1B	73	30	15	3/3	39	30.1	76.5%
OFD2B				0/3			
OFD3B	70	28	16	3/3	38	28.4	74.6%
OFD4B	103	56	28	3/3	62	37.9	60.8%
OFD5B				0/3			
OFD6B	31	15	15	3/3	20	9.2	45.4%
OFD1C	85	37	15	3/3	46	35.8	78.4%
OFD2C				0/3			
OFD3C	74	30	15	3/3	40	30.7	77.3%
OFD4C	104	65	28	2/3	66	38.0	57.9%
OFD5C				0/3			
OFD6C	31	12	12	3/3	18	11.0	59.8%
OFD1D	94	52	15	3/3	54	39.5	73.7%
OFD2D				0/3			
OFD3D	77	33	15	3/3	42	31.9	76.5%
OFD4D			27	1/3			
OFD5D				0/3			
OFD6D	72	23	19	3/3	38	29.5	77.7%
OFD1E			24	1/3			
OFD2E				0/3			
OFD3E	99	57		2/3	78	29.7	38.1%
OFD4E				0/3			
OFD5E				0/3			
OFD6E	72	27	22	3/3	40	27.5	68.3%
OFD1F			29	1/3			
OFD2F				0/3			
OFD3F	99	54		2/3	77	31.8	41.6%
OFD4F			33	1/3			
OFD5F				0/3			
OFD6F	72	30	22	3/3	41	26.9	65.0%

Scenario 12

Volume of Fuel: 3 L
Scenario: Fixed Quantity
Fuel: JP-8

Time to Alarm from Ignition (s)										
Test	Ofd012	Ofd100	Ofd101	Ofd102	Ofd112	Ofd113	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	19	11	2	6	44	20	4/4	10	7.3	77.1%
OFD2A			16				1/4			
OFD3A	14	10	3	6	39	17	4/4	8	4.8	58.0%
OFD4A	52	19	7	8		79	4/4	22	21.0	97.9%
OFD5A	87	19	10	17			4/4	33	36.0	108.4%
OFD6A	14	13	4	9	22	14	4/4	10	4.5	45.5%
OFD1B	34	13	3	6	27	19	4/4	14	14.0	99.8%
OFD2B							0/4			
OFD3B	35	13	4	7	37	16	4/4	15	14.0	95.0%
OFD4B	64	20	6	10		38	4/4	25	26.7	106.6%
OFD5B							0/4			
OFD6B	20	13	7	9	22	14	4/4	12	5.7	46.8%
OFD1C	29	13	3	5	33	20	4/4	13	11.8	94.5%
OFD2C							0/4			
OFD3C	14	13	4	7	39	17	4/4	10	4.8	50.5%
OFD4C	75	21	9	10		69	4/4	29	31.3	108.9%
OFD5C							0/4			
OFD6C	14	13	7	9	28	14	4/4	11	3.3	30.7%
OFD1D	30	12	2	6		36	4/4	13	12.4	99.0%
OFD2D							0/4			
OFD3D	15	12	4	7	51	22	4/4	10	4.9	51.9%
OFD4D	87	20	29	12			4/4	37	34.0	92.0%
OFD5D							0/4			
OFD6D	29	15	9	14	30	18	4/4	17	8.6	51.2%
OFD1E	76	20	12	11			4/4	30	31.1	104.5%
OFD2E							0/4			
OFD3E	77	18	35	40		28	4/4	43	24.9	58.5%
OFD4E	95	21	14	16			4/4	37	39.1	107.2%
OFD5E							0/4			
OFD6E	29	15	9	41	36	21	4/4	24	14.4	61.1%
OFD1F	68	21		11		63	3/4	33	30.4	91.3%
OFD2F							0/4			
OFD3F	76	18		51		28	3/4	48	29.1	60.2%
OFD4F	96	23	15	16			4/4	38	39.2	104.4%
OFD5F							0/4			
OFD6F	31	21	36	41	30	21	4/4	32	8.5	26.5%

Scenario 12

Volume of Fuel: 1 L
Scenario:Fixed Quantity
Fuel:JP-8

HRR at Times of Alarm (MW)	
Test	Ofd009
OFD1A	0
OFD2A	
OFD3A	0
OFD4A	0
OFD5A	
OFD6A	0
OFD1B	0
OFD2B	
OFD3B	0
OFD4B	0
OFD5B	
OFD6B	0
OFD1C	0
OFD2C	
OFD3C	0
OFD4C	0
OFD5C	
OFD6C	0
OFD1D	0
OFD2D	
OFD3D	0
OFD4D	
OFD5D	
OFD6D	0
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	0
OFD1F	
OFD2F	
OFD3F	0
OFD4F	
OFD5F	
OFD6F	0

Scenario 12

Volume of Fuel: 2 L
Scenario: Fixed Quantity
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)						
Test	Ofd010	Ofd011	Ofd099	Avg.	Std. Dev.	Variance
OFD1A	0.03	0.02	0.02	0.02	0.01	24.7%
OFD2A						
OFD3A	0.03	0.01	0.02	0.02	0.01	50.0%
OFD4A	0.09	0.06	0.02	0.06	0.04	62.0%
OFD5A						
OFD6A	0.01	0.01	0.02	0.01	0.01	43.3%
OFD1B	0.03	0.02	0.02	0.02	0.01	24.7%
OFD2B						
OFD3B	0.03	0.02	0.02	0.02	0.01	24.7%
OFD4B	0.1	0.1	0.05	0.08	0.03	34.6%
OFD5B						
OFD6B	0.01	0.01	0.02	0.01	0.01	43.3%
OFD1C	0.1	0.04	15	5.05	8.62	170.8%
OFD2C						
OFD3C	0.03	0.02	0.02	0.02	0.01	24.7%
OFD4C	0.1	0.17	0.05	0.11	0.06	56.5%
OFD5C						
OFD6C	0.01	0.01	0.01	0.01	0.00	0.0%
OFD1D	0.1	0.08	0.02	0.07	0.04	62.4%
OFD2D						
OFD3D	0.04	0.03	0.02	0.03	0.01	33.3%
OFD4D			0.04			
OFD5D						
OFD6D	0.03	0.01	0.02	0.02	0.01	50.0%
OFD1E			0.03			
OFD2E						
OFD3E	0.12	0.1		0.11	0.01	12.9%
OFD4E						
OFD5E						
OFD6E	0.03	0.02	0.02	0.02	0.01	24.7%
OFD1F			0.05			
OFD2F						
OFD3F	0.12	0.09		0.11	0.02	20.2%
OFD4F			0.11			
OFD5F						
OFD6F	0.03	0.02	0.02	0.02	0.01	24.7%

Scenario 12

Volume of Fuel: 3 L
Scenario: Fixed Quantity
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)							
Test	Ofd012	Ofd100	Ofd101	Ofd102	Avg.	Std. Dev.	Variance
OFD1A	0.02	0.01	0	0	0.01	0.01	127.7%
OFD2A			0.01				
OFD3A	0.01	0.07	0	0	0.02	0.03	168.3%
OFD4A	0.13	0.01	0	-0.01	0.03	0.07	201.6%
OFD5A	0.42	0.01	0	0	0.11	0.21	193.8%
OFD6A	0.01	0.01	0	-0.01	0.00	0.01	383.0%
OFD1B	0.03	0.01	0	0	0.01	0.01	141.4%
OFD2B							
OFD3B	0.04	0.01	0	-0.01	0.01	0.02	216.0%
OFD4B	0.28	0.01	0	-0.01	0.07	0.14	200.3%
OFD5B							
OFD6B	0.01	0.01	0	-0.01	0.00	0.01	383.0%
OFD1C	0.02	0.01	0	0	0.01	0.01	127.7%
OFD2C							
OFD3C	0.01	0.01	0	-0.01	0.00	0.01	383.0%
OFD4C	0.29	0.01	0	-0.01	0.07	0.15	200.3%
OFD5C							
OFD6C	0.01	0.01	0	-0.01	0.00	0.01	383.0%
OFD1D	0.02	0.01	0	0	0.01	0.01	127.7%
OFD2D							
OFD3D	0	0.01	0	-0.01	0.00	0.01	
OFD4D	0.42	0.01	0.3	-0.01	0.18	0.21	118.7%
OFD5D							
OFD6D	0.02	0.01	0	0	0.01	0.01	127.7%
OFD1E	0.38	0.01	0.01	-0.01	0.10	0.19	193.4%
OFD2E							
OFD3E	0.39	0.01	1.03	1.76	0.80	0.77	96.2%
OFD4E	0.51	0.01	0.01	0	0.13	0.25	190.0%
OFD5E							
OFD6E	0.02	0.01	0	1.83	0.47	0.91	195.7%
OFD1F	0.32	0.01		-0.01	0.11	0.19	173.5%
OFD2F							
OFD3F	0.38	0.01		1.62	0.67	0.84	125.9%
OFD4F	0.53	0.01	0.01	0	0.14	0.26	190.3%
OFD5F							
OFD6F	0.02	0.01	1.17	1.83	0.76	0.90	118.6%

Scenario 13

Fuel Flow Rate: .17 Lpm
Scenario: Confined (x-dir)
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd017	Ofd018	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	102		1/2			
OFD2A			0/2			
OFD3A	41	31	2/2	36	7.1	19.6%
OFD4A			0/2			
OFD5A			0/2			
OFD6A	16	26	2/2	21	7.1	33.7%
OFD1B	116		1/2			
OFD2B			0/2			
OFD3B	48		1/2			
OFD4B			0/2			
OFD5B			0/2			
OFD6B	22	26	2/2	24	2.8	11.8%
OFD1C			0/2			
OFD2C			0/2			
OFD3C	65		1/2	65		
OFD4C			0/2			
OFD5C			0/2			
OFD6C	22	26	2/2	24	2.8	11.8%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	66	109	2/2	88	30.4	34.7%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	47	29	2/2	38	12.7	33.5%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	53	47	2/2	50	4.2	8.5%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	50	59	2/2	55	6.4	11.7%

Scenario 13

Fuel Flow Type: .42 Lpm
Scenario: Confined (x-dir)
Fuel: JP-8

Time to Alarm from Ignition (s)							
Test	Ofd019	Ofd020	Ofd024	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A			49	2/4	43	8.5	19.7%
OFD2A				0/4			
OFD3A	25	28	17	4/4	22	5.6	25.8%
OFD4A			65	2/4	59	8.5	14.4%
OFD5A				0/4			
OFD6A	24	22	18	4/4	20	3.3	16.3%
OFD1B			48	2/4	45	4.9	11.1%
OFD2B				0/4			
OFD3B		29	29	3/4	30	1.2	3.9%
OFD4B				0/4			
OFD5B				0/4			
OFD6B	18	22	18	4/4	19	1.9	9.8%
OFD1C				1/4			
OFD2C				0/4			
OFD3C	57	32	29	4/4	37	13.2	35.5%
OFD4C				0/4			
OFD5C				0/4			
OFD6C	18	22	17	4/4	19	2.2	11.4%
OFD1D			59	1/4			
OFD2D				0/4			
OFD3D	50	39	29	4/4	38	9.1	24.2%
OFD4D				0/4			
OFD5D				0/4			
OFD6D	27	24	27	4/4	25	3.3	13.5%
OFD1E				0/4			
OFD2E				0/4			
OFD3E				0/4			
OFD4E				0/4			
OFD5E				0/4			
OFD6E	27	30	21	4/4	25	4.0	16.0%
OFD1F				0/4			
OFD2F				0/4			
OFD3F				0/4			
OFD4F				0/4			
OFD5F				0/4			
OFD6F	39	24	21	4/4	27	8.3	30.9%

Scenario 13

Fuel Flow Rate: .85 Lpm
Scenario: Confined (x-dir)
Fuel: JP-8

Time to Alarm from Ignition (s)							
Test	Ofd021	Ofd022	Ofd023	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	92	67	42	3/3	67	25.0	37.3%
OFD2A				0/3			
OFD3A	36	35	21	3/3	31	8.4	27.3%
OFD4A			73	1/3			
OFD5A				0/3			
OFD6A	23	28	19	3/3	23	4.5	19.3%
OFD1B			58	1/3			
OFD2B				0/3			
OFD3B	40	42	31	3/3	38	5.9	15.6%
OFD4B				0/3			
OFD5B				0/3			
OFD6B	32	31	23	3/3	29	4.9	17.2%
OFD1C	86		42	2/3	64	31.1	48.6%
OFD2C				0/3			
OFD3C	40	42	31	3/3	38	5.9	15.6%
OFD4C				0/3			
OFD5C				0/3			
OFD6C	32	19	19	3/3	23	7.5	32.2%
OFD1D				0/3			
OFD2D				0/3			
OFD3D	42	40	30	3/3	37	6.4	17.2%
OFD4D				0/3			
OFD5D				0/3			
OFD6D	39	32	28	3/3	33	5.6	16.9%
OFD1E				0/3			
OFD2E				0/3			
OFD3E				0/3			
OFD4E				0/3			
OFD5E				0/3			
OFD6E	39	41	26	3/3	35	8.1	23.1%
OFD1F				0/3			
OFD2F				0/3			
OFD3F				0/3			
OFD4F				0/3			
OFD5F				0/3			
OFD6F	36	40	26	3/3	34	7.2	21.2%

Scenario 13

Fuel Flow Rate: .17 Lpm
Scenario: Confined (x-dir)
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd017	Ofd018	Avg.	Std. Dev.	Variance
OFD1A	0.11				
OFD2A					
OFD3A	0.05	0.02	0.04	0.02	60.6%
OFD4A					
OFD5A					
OFD6A	0.02	0.02	0.02	0.00	0.0%
OFD1B	0.12				
OFD2B					
OFD3B	0.06				
OFD4B					
OFD5B					
OFD6B	0.03	0.02	0.03	0.01	28.3%
OFD1C					
OFD2C					
OFD3C	0.07		0.07		
OFD4C					
OFD5C					
OFD6C	0.03	0.02	0.03	0.01	28.3%
OFD1D					
OFD2D					
OFD3D	0.07	0.03	0.05	0.03	56.6%
OFD4D					
OFD5D					
OFD6D	0.06	0.02	0.04	0.03	70.7%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.07	0.02	0.05	0.04	78.6%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.07	0.03	0.05	0.03	56.6%

Scenario 13

Fuel Flow Type: .42 Lpm
Scenario: Confined (x-dir)
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)						
Test	Ofd019	Ofd020	Ofd024	Avg.	Std. Dev.	Variance
OFD1A			0.12	0.11	0.01	12.9%
OFD2A						
OFD3A	0.02	0.04	0.04	0.04	0.01	33.6%
OFD4A			0.14	0.14	0.00	0.0%
OFD5A						
OFD6A	0.02	0.04	0.04	0.04	0.01	33.6%
OFD1B			0.12	0.12	0.00	0.0%
OFD2B						
OFD3B		0.04	0.07	0.07	0.03	37.7%
OFD4B						
OFD5B						
OFD6B	0.01	0.04	0.04	0.04	0.02	55.0%
OFD1C						
OFD2C						
OFD3C	0.03	0.05	0.07	0.06	0.03	43.0%
OFD4C						
OFD5C						
OFD6C	0.01	0.04	0.04	0.04	0.02	55.0%
OFD1D			0.13			
OFD2D						
OFD3D	0.03	0.06	0.07	0.06	0.03	40.0%
OFD4D						
OFD5D						
OFD6D	0.03	0.04	0.06	0.05	0.02	31.6%
OFD1E						
OFD2E						
OFD3E						
OFD4E						
OFD5E						
OFD6E	0.03	0.05	0.07	0.05	0.02	32.5%
OFD1F						
OFD2F						
OFD3F						
OFD4F						
OFD5F						
OFD6F	0.03	0.04	0.05	0.05	0.02	36.0%

Scenario 13

Fuel Flow Rate: .85 Lpm
Scenario: Confined (x-dir)
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)						
Test	Ofd021	Ofd022	Ofd023	Avg.	Std. Dev.	Variance
OFD1A	0.11	0.11	0.09	0.10	0.01	11.2%
OFD2A						
OFD3A	0.06	0.08	0.05	0.06	0.02	24.1%
OFD4A			0.12			
OFD5A						
OFD6A	0.03	0.06	0.04	0.04	0.02	35.3%
OFD1B			0.09			
OFD2B						
OFD3B	0.06	0.09	0.06	0.07	0.02	24.7%
OFD4B						
OFD5B						
OFD6B	0.06	0.06	0.05	0.06	0.01	10.2%
OFD1C	0.11		0.09	0.10	0.01	14.1%
OFD2C						
OFD3C	0.06	0.09	0.06	0.07	0.02	24.7%
OFD4C						
OFD5C						
OFD6C	0.06	0.04	0.04	0.05	0.01	24.7%
OFD1D						
OFD2D						
OFD3D	0.06	0.09	0.06	0.07	0.02	24.7%
OFD4D						
OFD5D						
OFD6D	0.06	0.07	0.06	0.06	0.01	9.1%
OFD1E						
OFD2E						
OFD3E						
OFD4E						
OFD5E						
OFD6E	0.06	0.09	0.05	0.07	0.02	31.2%
OFD1F						
OFD2F						
OFD3F						
OFD4F						
OFD5F						
OFD6F	0.06	0.09	0.05	0.07	0.02	31.2%

Scenario 14

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir)
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd026	Ofd030	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A			0/2			
OFD2A			0/2			
OFD3A	34	24	2/2	29	7.1	24.4%
OFD4A			0/2			
OFD5A			0/2			
OFD6A	22	19	2/2	21	2.1	10.3%
OFD1B			0/2			
OFD2B			0/2			
OFD3B	192	68	2/2	130	87.7	67.4%
OFD4B			0/2			
OFD5B			0/2			
OFD6B	22	18	2/2	20	2.8	14.1%
OFD1C			0/2			
OFD2C			0/2			
OFD3C	192	57	2/2	125	95.5	76.7%
OFD4C			0/2			
OFD5C			0/2			
OFD6C	22	16	2/2	19	4.2	22.3%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	192	54	2/2	123	97.6	79.3%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	27	24	2/2	26	2.1	8.3%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	57	27	2/2	42	21.2	50.5%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	57	24	2/2	41	23.3	57.6%

Scenario 14

Fuel Flow Type: .42 Lpm
Scenario: Confined (y-dir)
Fuel: JP-8

Time to Alarm from Ignition (s)	
Test	Ofd027
OFD1A	120
OFD2A	
OFD3A	27
OFD4A	118
OFD5A	
OFD6A	21
OFD1B	
OFD2B	
OFD3B	59
OFD4B	
OFD5B	
OFD6B	21
OFD1C	
OFD2C	
OFD3C	59
OFD4C	
OFD5C	
OFD6C	21
OFD1D	
OFD2D	
OFD3D	60
OFD4D	
OFD5D	
OFD6D	34
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	39
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	52

Scenario 14

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir)
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd028	Ofd029	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	42	66	2/2	54	17.0	31.4%
OFD2A			0/2			
OFD3A	21	21	2/2	21	0.0	0.0%
OFD4A	81	82	2/2	82	0.7	0.9%
OFD5A			0/2			
OFD6A	20	22	2/2	21	1.4	6.7%
OFD1B	84	90	2/2	87	4.2	4.9%
OFD2B			0/2			
OFD3B	41	32	2/2	37	6.4	17.4%
OFD4B	88		1/2			
OFD5B			0/2			
OFD6B	23	19	2/2	21	2.8	13.5%
OFD1C	56	79	2/2	68	16.3	24.1%
OFD2C			0/2			
OFD3C	40	32	2/2	36	5.7	15.7%
OFD4C			0/2			
OFD5C			0/2			
OFD6C	20	19	2/2	20	0.7	3.6%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	38	32	2/2	35	4.2	12.1%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	24	21	2/2	23	2.1	9.4%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	27	37	2/2	32	7.1	22.1%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	27	37	2/2	32	7.1	22.1%

Scenario 14

Fuel Flow Rate: 1.7 Lpm
Scenario: Confined (y-dir)
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd038	Ofd039	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	41	44	2/2	43	2.1	5.0%
OFD2A			0/2			
OFD3A	25	22	2/2	24	2.1	9.0%
OFD4A		46	1/2			
OFD5A			0/2			
OFD6A	22	22	2/2	22	0.0	0.0%
OFD1B	60	52	2/2	56	5.7	10.1%
OFD2B			0/2			
OFD3B	32	33	2/2	33	0.7	2.2%
OFD4B		80	1/2			
OFD5B			0/2			
OFD6B	19	22	2/2	21	2.1	10.3%
OFD1C		43	1/2			
OFD2C			0/2			
OFD3C	32	33	2/2	33	0.7	2.2%
OFD4C		54	1/2			
OFD5C			0/2			
OFD6C	18	19	2/2	19	0.7	3.8%
OFD1D	63	44	2/2	54	13.4	25.1%
OFD2D			0/2			
OFD3D	33	35	2/2	34	1.4	4.2%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	27	33	2/2	30	4.2	14.1%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	39	45	2/2	42	4.2	10.1%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	36	30	2/2	33	4.2	12.9%

Scenario 14

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir)
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd026	Ofd030	Avg.	Std. Dev.	Variance
OFD1A					
OFD2A					
OFD3A	0.06	0.07	0.07	0.01	10.9%
OFD4A					
OFD5A					
OFD6A	0.04	0.06	0.05	0.01	28.3%
OFD1B					
OFD2B					
OFD3B	0.09	0.09	0.09	0.00	0.0%
OFD4B					
OFD5B					
OFD6B	0.04	0.06	0.05	0.01	28.3%
OFD1C					
OFD2C					
OFD3C	0.09	0.09	0.09	0.00	0.0%
OFD4C					
OFD5C					
OFD6C	0.04	0.06	0.05	0.01	28.3%
OFD1D					
OFD2D					
OFD3D	0.09	0.09	0.09	0.00	0.0%
OFD4D					
OFD5D					
OFD6D	0.05	0.07	0.06	0.01	23.6%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.06	0.07	0.07	0.01	10.9%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.06	0.07	0.07	0.01	10.9%

Scenario 14

Fuel Flow Type: .42 Lpm
Scenario: Confined (y-dir)
Fuel: JP-8

HRR at Time of Alarm (MW)	
Test	Ofd027
OFD1A	0.16
OFD2A	
OFD3A	0.06
OFD4A	0.16
OFD5A	
OFD6A	0.05
OFD1B	
OFD2B	
OFD3B	0.12
OFD4B	
OFD5B	
OFD6B	0.05
OFD1C	
OFD2C	
OFD3C	0.12
OFD4C	
OFD5C	
OFD6C	0.05
OFD1D	
OFD2D	
OFD3D	0.12
OFD4D	
OFD5D	
OFD6D	0.08
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	0.09
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	0.10

Scenario 14

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir)
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd028	Ofd029	Avg.	Std. Dev.	Variance
OFD1A	0.12	0.17	0.15	0.04	24.4%
OFD2A					
OFD3A	0.07	0.06	0.07	0.01	10.9%
OFD4A	0.19	0.18	0.19	0.01	3.8%
OFD5A					
OFD6A	0.06	0.07	0.07	0.01	10.9%
OFD1B	0.20	0.19	0.20	0.01	3.6%
OFD2B					
OFD3B	0.12	0.10	0.11	0.01	12.9%
OFD4B	0.20				
OFD5B					
OFD6B	0.08	0.05	0.07	0.02	32.6%
OFD1C	0.15	0.19	0.17	0.03	16.6%
OFD2C					
OFD3C	0.12	0.10	0.11	0.01	12.9%
OFD4C					
OFD5C					
OFD6C	0.06	0.05	0.06	0.01	12.9%
OFD1D					
OFD2D					
OFD3D	0.12	0.10	0.11	0.01	12.9%
OFD4D					
OFD5D					
OFD6D	0.08	0.06	0.07	0.01	20.2%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.09	0.12	0.11	0.02	20.2%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.09	0.12	0.11	0.02	20.2%

Scenario 14

Fuel Flow Rate: 1.7 Lpm
Scenario: Confined (y-dir)
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd038	Ofd039	Avg.	Std. Dev.	Variance
OFD1A	0.12	0.11	0.12	0.01	6.1%
OFD2A					
OFD3A	0.08	0.04	0.06	0.03	47.1%
OFD4A		0.12			
OFD5A					
OFD6A	0.06	0.04	0.05	0.01	28.3%
OFD1B	0.16	0.13	0.15	0.02	14.6%
OFD2B					
OFD3B	0.10	0.07	0.09	0.02	25.0%
OFD4B		0.17			
OFD5B					
OFD6B	0.05	0.04	0.05	0.01	15.7%
OFD1C		0.11			
OFD2C					
OFD3C	0.10	0.07	0.09	0.02	25.0%
OFD4C		0.13			
OFD5C					
OFD6C	0.05	0.04	0.05	0.01	15.7%
OFD1D	0.16	0.11	0.14	0.04	26.2%
OFD2D					
OFD3D	0.10	0.07	0.09	0.02	25.0%
OFD4D					
OFD5D					
OFD6D	0.08	0.07	0.08	0.01	9.4%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.11	0.12	0.12	0.01	6.1%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.11	0.06	0.09	0.04	41.6%

Scenario 15

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir) w/ chopped UV/IR
Fuel: JP-8

Time to Alarm from Ignition (s)	
Test	Ofd033
OFD1A	
OFD2A	
OFD3A	10
OFD4A	
OFD5A	
OFD6A	9
OFD1B	
OFD2B	
OFD3B	45
OFD4B	
OFD5B	
OFD6B	15
OFD1C	
OFD2C	
OFD3C	24
OFD4C	
OFD5C	
OFD6C	12
OFD1D	
OFD2D	
OFD3D	26
OFD4D	
OFD5D	
OFD6D	15
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	27
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	27

Scenario 15

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir) w/ mod. UV/IR
Fuel: JP-8

Time to Alarm from Ignition (s)						
Test	Ofd031	Ofd032	Alarms/test	Avg.	Std. Dev.	Variance
OFD1A			0/2			
OFD2A			0/2			
OFD3A	20	20	2/2	20	0.0	0.0%
OFD4A			0/2			
OFD5A			0/2			
OFD6A	16	25	2/2	21	6.4	31.0%
OFD1B			0/2			
OFD2B			0/2			
OFD3B	30	61	2/2	46	21.9	48.2%
OFD4B			0/2			
OFD5B			0/2			
OFD6B	31	25	2/2	28	4.2	15.2%
OFD1C			0/2			
OFD2C			0/2			
OFD3C	27	30	2/2	29	2.1	7.4%
OFD4C			0/2			
OFD5C			0/2			
OFD6C	22	18	2/2	20	2.8	14.1%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	30	35	2/2	33	3.5	10.9%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	27	23	2/2	25	2.8	11.3%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	30	47	2/2	39	12.0	31.2%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	35	26	2/2	31	6.4	20.9%

Scenario 15

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir) w/ chopped UV/IR
Fuel: JP-8

HRR at Time of Alarm (MW)	
Test	Ofd033
OFD1A	
OFD2A	
OFD3A	0.01
OFD4A	
OFD5A	
OFD6A	0.01
OFD1B	
OFD2B	
OFD3B	0.09
OFD4B	
OFD5B	
OFD6B	0.01
OFD1C	
OFD2C	
OFD3C	0.04
OFD4C	
OFD5C	
OFD6C	0.01
OFD1D	
OFD2D	
OFD3D	0.04
OFD4D	
OFD5D	
OFD6D	0.01
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	0.05
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	0.05

Scenario 15

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir) w/ mod. UV/IR
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd031	Ofd032	Average	Standard Deviation	Variance
OFD1A					
OFD2A					
OFD3A	0.06	0.06	0.06	0.00	0.0%
OFD4A					
OFD5A					
OFD6A	0.04	0.08	0.06	0.03	47.1%
OFD1B					
OFD2B					
OFD3B	0.10	0.17	0.14	0.05	36.7%
OFD4B					
OFD5B					
OFD6B	0.10	0.08	0.09	0.01	15.7%
OFD1C					
OFD2C					
OFD3C	0.09	0.10	0.10	0.01	7.4%
OFD4C					
OFD5C					
OFD6C	0.07	0.05	0.06	0.01	23.6%
OFD1D					
OFD2D					
OFD3D	0.10	0.12	0.11	0.01	12.9%
OFD4D					
OFD5D					
OFD6D	0.09	0.07	0.08	0.01	17.7%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.10	0.15	0.13	0.04	28.3%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.11	0.09	0.10	0.01	14.1%

Scenario 16

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir) w/ chopped IR @20 m
Fuel: JP-8

Time to Alarm from Ignition (s)

Test	Ofd034
OFD1A	190
OFD2A	
OFD3A	39
OFD4A	
OFD5A	
OFD6A	14
OFD1B	
OFD2B	
OFD3B	189
OFD4B	
OFD5B	
OFD6B	17
OFD1C	
OFD2C	
OFD3C	199
OFD4C	
OFD5C	
OFD6C	23
OFD1D	
OFD2D	
OFD3D	24
OFD4D	
OFD5D	
OFD6D	18
OFD1E	
OFD2E	
OFD3E	-
OFD4E	
OFD5E	
OFD6E	29
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	18

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir) w/ chopped IR @20 m
Fuel: JP-8

Test	Ofd036
OFD1A	46
OFD2A	
OFD3A	41
OFD4A	
OFD5A	
OFD6A	29
OFD1B	
OFD2B	
OFD3B	
OFD4B	
OFD5B	
OFD6B	29
OFD1C	82
OFD2C	
OFD3C	
OFD4C	
OFD5C	
OFD6C	23
OFD1D	
OFD2D	
OFD3D	20
OFD4D	
OFD5D	
OFD6D	27
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	30
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	39

Scenario 16

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir) w/ chopped IR @20 m
Fuel: JP-8

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir) w/ chopped IR @20 m
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)

Test	Ofd034
OFD1A	0.1
OFD2A	
OFD3A	0.02
OFD4A	
OFD5A	
OFD6A	0.01
OFD1B	
OFD2B	
OFD3B	0.1
OFD4B	
OFD5B	
OFD6B	0.01
OFD1C	
OFD2C	
OFD3C	0.11
OFD4C	
OFD5C	
OFD6C	0.01
OFD1D	
OFD2D	
OFD3D	0.02
OFD4D	
OFD5D	
OFD6D	0.01
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	0.02
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	0.01

Test	Ofd036
OFD1A	0.11
OFD2A	
OFD3A	0.11
OFD4A	
OFD5A	
OFD6A	0.09
OFD1B	
OFD2B	
OFD3B	
OFD4B	
OFD5B	
OFD6B	0.09
OFD1C	0.15
OFD2C	
OFD3C	
OFD4C	
OFD5C	
OFD6C	0.06
OFD1D	
OFD2D	
OFD3D	0.05
OFD4D	
OFD5D	
OFD6D	0.08
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	0.09
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	0.11

Scenario 17

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir) w/ chopped IR @26 m
Fuel: JP-8

Time to Alarm from Ignition (s)

Test	Ofd035
OFD1A	
OFD2A	
OFD3A	
OFD4A	
OFD5A	
OFD6A	27
OFD1B	
OFD2B	101
OFD3B	
OFD4B	
OFD5B	
OFD6B	50
OFD1C	
OFD2C	
OFD3C	
OFD4C	
OFD5C	
OFD6C	66
OFD1D	
OFD2D	
OFD3D	73
OFD4D	
OFD5D	
OFD6D	30
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	52
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	42

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir) w/ chopped IR @26 m
Fuel: JP-8

Test	Ofd037
OFD1A	34
OFD2A	
OFD3A	
OFD4A	
OFD5A	
OFD6A	24
OFD1B	41
OFD2B	84
OFD3B	
OFD4B	
OFD5B	
OFD6B	24
OFD1C	61
OFD2C	
OFD3C	
OFD4C	
OFD5C	125
OFD6C	29
OFD1D	
OFD2D	
OFD3D	24
OFD4D	
OFD5D	
OFD6D	20
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	25
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	32

Scenario 17

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir) w/ chopped IR @26 m
Fuel: JP-8

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir) w/ chopped IR @26 m
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)

Test	Ofd035
OFD1A	
OFD2A	
OFD3A	
OFD4A	
OFD5A	
OFD6A	0.03
OFD1B	
OFD2B	0.08
OFD3B	
OFD4B	
OFD5B	
OFD6B	0.05
OFD1C	
OFD2C	
OFD3C	
OFD4C	
OFD5C	
OFD6C	0.06
OFD1D	
OFD2D	
OFD3D	0.06
OFD4D	
OFD5D	
OFD6D	0.03
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	0.05
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	0.04

Test	Ofd037
OFD1A	0.1
OFD2A	
OFD3A	
OFD4A	
OFD5A	
OFD6A	0.07
OFD1B	0.14
OFD2B	0.22
OFD3B	
OFD4B	
OFD5B	
OFD6B	0.07
OFD1C	0.19
OFD2C	
OFD3C	
OFD4C	
OFD5C	0.27
OFD6C	0.08
OFD1D	
OFD2D	
OFD3D	0.07
OFD4D	
OFD5D	
OFD6D	0.06
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	0.07
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	0.1

Scenario 18

Scenario: Pan Fire
Pan Size: 0.3 x 0.3 m
Fuel: JP-8

Test	Ofd106
OFD1A	
OFD2A	
OFD3A	51
OFD4A	
OFD5A	
OFD6A	37
OFD1B	
OFD2B	
OFD3B	65
OFD4B	
OFD5B	
OFD6B	37
OFD1C	
OFD2C	
OFD3C	66
OFD4C	
OFD5C	
OFD6C	34
OFD1D	
OFD2D	
OFD3D	64
OFD4D	
OFD5D	
OFD6D	53
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	56
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	68

Scenario: Pan Fire @ 15 m
Pan Size: 0.3 x 0.3 m
Fuel: JP-8

Time to Alarm from Ignition (s)

Test	Ofd107
OFD1A	30
OFD2A	
OFD3A	24
OFD4A	48
OFD5A	55
OFD6A	11
OFD1B	30
OFD2B	
OFD3B	24
OFD4B	50
OFD5B	
OFD6B	10
OFD1C	32
OFD2C	
OFD3C	24
OFD4C	59
OFD5C	
OFD6C	10
OFD1D	
OFD2D	
OFD3D	30
OFD4D	
OFD5D	
OFD6D	30
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	30
OFD1F	
OFD2F	
OFD3F	87
OFD4F	
OFD5F	
OFD6F	30

Scenario: Pan Fire @ -15.2 m
Pan Size: 0.3 x 0.3 m
Fuel: JP-8

Test	Ofd108
OFD1A	
OFD2A	
OFD3A	62
OFD4A	
OFD5A	
OFD6A	56
OFD1B	
OFD2B	
OFD3B	
OFD4B	
OFD5B	
OFD6B	77
OFD1C	
OFD2C	
OFD3C	
OFD4C	
OFD5C	
OFD6C	68
OFD1D	
OFD2D	
OFD3D	90
OFD4D	
OFD5D	
OFD6D	191
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	89
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	86

Scenario 18

Scenario: Pan Fire
Pan Size: 0.6 x 0.6 m
Fuel: JP-8

Time to Alarm from Ignition (s)									
Test	Ofd013	Ofd103	Ofd104	Ofd116	Ofd117	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	32	40	33	37	31	3/3	35	4.4	12.5%
OFD2A						0/3			
OFD3A	19	20	16	22	13	3/3	18	2.1	11.4%
OFD4A	38	31	32	41	29	3/3	34	3.8	11.2%
OFD5A	63	43	62	48	79	3/3	56	11.3	20.1%
OFD6A	21	22	19	24	11	3/3	21	1.5	7.4%
OFD1B	41	43	30	30	27	3/3	38	7.0	18.4%
OFD2B						0/3			
OFD3B	21	22	18	21	23	3/3	20	2.1	10.2%
OFD4B	37	45	43	32	22	3/3	42	4.2	10.0%
OFD5B				49	79	0/3			
OFD6B	21	22	16	24	14	3/3	20	3.2	16.3%
OFD1C	39	47	28	39	33	3/3	38	9.5	25.1%
OFD2C						0/3			
OFD3C	21	22	18	21	13	3/3	20	2.1	10.2%
OFD4C	44	43	47	39	35	3/3	45	2.1	4.7%
OFD5C				48	79	0/3			
OFD6C	21	22	16	24	11	3/3	20	3.2	16.3%
OFD1D	66	41	62	49	108	3/3	56	13.4	23.8%
OFD2D						0/3			
OFD3D	21	22	18	23	16	3/3	20	2.1	10.2%
OFD4D	46	43	41	44	51	3/3	43	2.5	5.8%
OFD5D						0/3			
OFD6D	23	25	20	29	21	3/3	23	2.5	11.1%
OFD1E					92	0/3			
OFD2E						0/3			
OFD3E	44	43	36	29	21	3/3	41	4.4	10.6%
OFD4E	91	99	80	44	46	3/3	90	9.5	10.6%
OFD5E						0/3			
OFD6E	26	25	20	25	21	3/3	24	3.2	13.6%
OFD1F	139			57	80	1/3			
OFD2F						0/3			
OFD3F	41	39	34	29	21	3/3	38	3.6	9.5%
OFD4F	73	64	74	49	55	3/3	70	5.5	7.8%
OFD5F						0/3			
OFD6F	23	25	26	25	20	3/3	25	1.5	6.2%

Scenario 18

Scenario: Pan Fire
Pan Size: 0.91 m dia
Fuel: JP-8

Time to Alarm from Ignition (s)									
Test	Ofd015	Ofd105	Ofd118	Ofd110	Ofd111	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	19	38	33	62	40	2/2	29	13.4	47.1%
OFD2A	47	135				2/2	115	62.2	54.1%
OFD3A	15	17	20	62	71	2/2	16	1.4	8.8%
OFD4A	22	24	31	64	63	2/2	23	1.4	6.1%
OFD5A	35	45	43	65	82	2/2	40	7.1	17.7%
OFD6A	17	21	22	28	72	2/2	19	2.8	14.9%
OFD1B	26	39	30	67	93	2/2	33	9.2	28.3%
OFD2B						0/2			
OFD3B	17	19	19	65	94	2/2	18	1.4	7.9%
OFD4B	32	35	30	68	93	2/2	34	2.1	6.3%
OFD5B			55			0/2			
OFD6B	16	21	22	70	54	2/2	19	3.5	19.1%
OFD1C	32	43	29	65	89	2/2	38	7.8	20.7%
OFD2C						0/2			
OFD3C	17	20	20			2/2	19	2.1	11.5%
OFD4C	33	35	32	68	95	2/2	34	1.4	4.2%
OFD5C			46			0/2			
OFD6C	16	21	22	70	102	2/2	19	3.5	19.1%
OFD1D	38	55	49	40	42	2/2	47	12.0	25.9%
OFD2D						0/2			
OFD3D	16	19	25	30	16	2/2	18	2.1	12.1%
OFD4D	32	38	38	49	63	2/2	35	4.2	12.1%
OFD5D	81		87			1/2			
OFD6D	19	21	22	30	20	2/2	20	1.4	7.1%
OFD1E			59	124	92	0/2			
OFD2E						0/2			
OFD3E	31	110	27	44	21	2/2	71	55.9	79.2%
OFD4E	41	45	33	47	39	2/2	43	2.8	6.6%
OFD5E			133			0/2			
OFD6E	19	24	25	31	26	2/2	22	3.5	16.4%
OFD1F	69		66	73		1/2			
OFD2F						0/2			
OFD3F	25		27		22	1/2			
OFD4F	41	43	38	49	57	2/2	42	1.4	3.4%
OFD5F			86			0/2			
OFD6F	25	24	25	33	26	2/2	25	0.7	2.9%

Scenario 18

Scenario: Pan Fire
Pan Size: 0.3 x 0.3 m
Fuel: JP-8

HRR at Time of Alarm (MW)	
Test	Ofd106
OFD1A	
OFD2A	
OFD3A	0.06
OFD4A	
OFD5A	
OFD6A	0.04
OFD1B	
OFD2B	
OFD3B	0.06
OFD4B	
OFD5B	
OFD6B	0.04
OFD1C	
OFD2C	
OFD3C	0.07
OFD4C	
OFD5C	
OFD6C	0.04
OFD1D	
OFD2D	
OFD3D	0.07
OFD4D	
OFD5D	
OFD6D	0.06
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	0.06
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	0.07

Scenario 18

Scenario: Pan Fire
Pan Size: 0.6 x 0.6 m
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)						
Test	Ofd013	Ofd103	Ofd104	Avg.	Std. Dev.	Variance
OFD1A	0.21	0.27	0.25	0.24	0.03	13%
OFD2A						
OFD3A	0.1	0.09	0.1	0.10	0.01	6%
OFD4A	0.26	0.19	0.24	0.23	0.04	16%
OFD5A	0.35	0.3	0.34	0.33	0.03	8%
OFD6A	0.11	0.12	0.13	0.12	0.01	8%
OFD1B	0.28	0.29	0.22	0.26	0.04	14%
OFD2B						
OFD3B	0.11	0.12	0.12	0.12	0.01	5%
OFD4B	0.25	0.3	0.31	0.29	0.03	11%
OFD5B						
OFD6B	0.11	0.12	0.1	0.11	0.01	9%
OFD1C	0.27	0.31	0.21	0.26	0.05	19%
OFD2C						
OFD3C	0.11	0.12	0.12	0.12	0.01	5%
OFD4C	0.3	0.29	0.32	0.30	0.02	5%
OFD5C						
OFD6C	0.11	0.12	0.1	0.11	0.01	9%
OFD1D	0.35	0.28	0.34	0.32	0.04	12%
OFD2D						
OFD3D	0.11	0.12	0.12	0.12	0.01	5%
OFD4D	0.3	0.29	0.3	0.30	0.01	2%
OFD5D						
OFD6D	0.13	0.13	0.14	0.13	0.01	4%
OFD1E						
OFD2E						
OFD3E	0.3	0.29	0.27	0.29	0.02	5%
OFD4E	0.35	0.36	0.37	0.36	0.01	3%
OFD5E						
OFD6E	0.16	0.13	0.14	0.14	0.02	11%
OFD1F	0.38					
OFD2F						
OFD3F	0.28	0.26	0.26	0.27	0.01	4%
OFD4F	0.36	0.35	0.37	0.36	0.01	3%
OFD5F						
OFD6F	0.13	0.13	0.19	0.15	0.03	23%

Scenario 18

Scenario: Pan Fire
Pan Size: 0.91 m dia
Fuel: JP-8

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd015	Ofd105	Avg.	Std. Dev.	Variance
OFD1A	0.22	0.48	0.35	0.18	53%
OFD2A	0.6	0.68	0.64	0.06	9%
OFD3A	0.16	0.14	0.15	0.01	9%
OFD4A	0.27	0.24	0.26	0.02	8%
OFD5A	0.47	0.58	0.53	0.08	15%
OFD6A	0.19	0.2	0.20	0.01	4%
OFD1B	0.32	0.5	0.41	0.13	31%
OFD2B					
OFD3B	0.19	0.17	0.18	0.01	8%
OFD4B	0.41	0.43	0.42	0.01	3%
OFD5B					
OFD6B	0.17	0.2	0.19	0.02	11%
OFD1C	0.41	0.56	0.49	0.11	22%
OFD2C					
OFD3C	0.19	0.18	0.19	0.01	4%
OFD4C	0.43	0.43	0.43	0.00	0%
OFD5C					
OFD6C	0.17	0.2	0.19	0.02	11%
OFD1D	0.52	0.66	0.59	0.10	17%
OFD2D					
OFD3D	0.17	0.17	0.17	0.00	0%
OFD4D	0.41	0.48	0.45	0.05	11%
OFD5D	0.62				
OFD6D	0.22	0.2	0.21	0.01	7%
OFD1E					
OFD2E					
OFD3E	0.4	0.62	0.51	0.16	31%
OFD4E	0.55	0.58	0.57	0.02	4%
OFD5E					
OFD6E	0.22	0.24	0.23	0.01	6%
OFD1F	0.61				
OFD2F					
OFD3F	0.31				
OFD4F	0.55	0.56	0.56	0.01	1%
OFD5F					
OFD6F	0.31	0.24	0.28	0.05	18%

Scenario 19

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined
Fuel: JP-5

Time to Alarm from Ignition (s)							
Test	Ofd096	Ofd097	Ofd098	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	31		28	2/3	30	2.1	7.2%
OFD2A				0/3			
OFD3A	25	21	19	3/3	22	3.1	14.1%
OFD4A				0/3			
OFD5A				0/3			
OFD6A	22	18	19	3/3	20	2.1	10.6%
OFD1B				1/3			
OFD2B				0/3			
OFD3B	45	66	29	3/3	47	18.6	39.8%
OFD4B				0/3			
OFD5B				0/3			
OFD6B	19	18	19	3/3	19	0.6	3.1%
OFD1C	42		70	2/3	56	19.8	35.4%
OFD2C				0/3			
OFD3C	45	62	29	2/3	45	16.5	36.4%
OFD4C				0/3			
OFD5C				0/3			
OFD6C	25	18	22	3/3	22	3.5	16.2%
OFD1D				0/3			
OFD2D				0/3			
OFD3D	37	62	29	2/3	43	17.2	40.3%
OFD4D				0/3			
OFD5D				0/3			
OFD6D	30	23	23	3/3	25	4.0	16.0%
OFD1E				0/3			
OFD2E				0/3			
OFD3E				0/3			
OFD4E				0/3			
OFD5E				0/3			
OFD6E	30	26	23	3/3	26	3.5	13.3%
OFD1F				0/3			
OFD2F				0/3			
OFD3F				0/3			
OFD4F				0/3			
OFD5F				0/3			
OFD6F	30	23	23	3/3	25	4.0	16.0%

Scenario 19

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined
Fuel: JP-5

Time to Alarm from Ignition (s)								
Test	Ofd092	Ofd093	Ofd094	Ofd095	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	22	55	29	23	4/4	32	15.5	48.0%
OFD2A	71				1/4			
OFD3A	24	46	27	26	4/4	31	10.2	33.3%
OFD4A	30	67	37	32	4/4	42	17.3	41.6%
OFD5A	36	75	59	49	4/4	55	16.5	30.1%
OFD6A		40	25	26	3/4	30	8.4	27.6%
OFD1B	27	57	26	26	4/4	34	15.3	45.1%
OFD2B					0/4			
OFD3B	27	61	29	29	4/4	37	16.4	44.8%
OFD4B	33	68	41	35	4/4	44	16.2	36.6%
OFD5B					0/4			
OFD6B		46	25	28	3/4	33	11.4	34.4%
OFD1C	24	56	30	25	4/4	34	15.1	44.6%
OFD2C					0/4			
OFD3C	26	61	29	29	4/4	36	16.6	45.7%
OFD4C	35	68	40	36	4/4	45	15.6	35.0%
OFD5C					0/4			
OFD6C	25	43	25	22	4/4	29	9.6	33.4%
OFD1D	24	62	32	27	4/4	36	17.5	48.2%
OFD2D					0/4			
OFD3D	25	60	29	28	4/4	36	16.4	46.3%
OFD4D	36	73	45	40	4/4	49	16.7	34.5%
OFD5D					0/4			
OFD6D	25	45	33	32	4/4	34	8.3	24.6%
OFD1E	38	71	57	39	4/4	51	15.8	30.8%
OFD2E					0/4			
OFD3E	33	70	42	40	4/4	46	16.3	35.2%
OFD4E	52		62	53	3/4	56	5.5	9.9%
OFD5E					0/4			
OFD6E	31	66	33	32	4/4	41	17.0	42.0%
OFD1F	40	78	46	47	4/4	53	17.1	32.4%
OFD2F					0/4			
OFD3F	31	68	42		3/4	47	19.0	40.4%
OFD4F	38	84	64	48	4/4	59	20.1	34.3%
OFD5F					0/4			
OFD6F	31	57	33	32	4/4	38	12.5	32.7%

Scenario 19

Fuel Flow Rate: .17 Lpm
Scenario: Unconfined
Fuel: JP-5

Heat Release Rates at Time of Alarm (MW)						
Test	Ofd096	Ofd097	Ofd098	Avg.	Std. Dev.	Variance
OFD1A	0.09		0.09	0.09	0.00	0.0%
OFD2A						
OFD3A	0.07	0.07	0.05	0.06	0.01	18.2%
OFD4A						
OFD5A						
OFD6A	0.06	0.06	0.05	0.06	0.01	10.2%
OFD1B						
OFD2B						
OFD3B	0.12	0.11	0.10	0.11	0.01	9.1%
OFD4B						
OFD5B						
OFD6B	0.05	0.06	0.05	0.05	0.01	10.8%
OFD1C	0.12		0.12	0.12	0.00	0.0%
OFD2C						
OFD3C	0.12	0.11	0.10	0.11	0.01	9.1%
OFD4C						
OFD5C						
OFD6C	0.07	0.06	0.07	0.07	0.01	8.7%
OFD1D						
OFD2D						
OFD3D	0.11	0.11	0.10	0.11	0.01	5.4%
OFD4D						
OFD5D						
OFD6D	0.09	0.08	0.07	0.08	0.01	12.5%
OFD1E						
OFD2E						
OFD3E						
OFD4E						
OFD5E						
OFD6E	0.09	0.08	0.07	0.08	0.01	12.5%
OFD1F						
OFD2F						
OFD3F						
OFD4F						
OFD5F						
OFD6F	0.09	0.08	0.07	0.08	0.01	12.5%

Scenario 19

Fuel Flow Rate: 1.7 Lpm
Scenario: Unconfined
Fuel: JP-5

Heat Release Rates at Time of Alarm (MW)							
Test	Ofd092	Ofd093	Ofd094	Ofd095	Avg.	Std. Dev.	Variance
OFD1A	0.16	0.15	0.15	0.13	0.15	0.01	8.5%
OFD2A	0.86						
OFD3A	0.21	0.07	0.12	0.19	0.15	0.06	43.7%
OFD4A	0.38	0.5	0.38	0.35	0.40	0.07	16.5%
OFD5A	0.59	0.86	0.82	0.75	0.76	0.12	15.8%
OFD6A		0.03	0.09	0.19	0.10	0.08	78.2%
OFD1B	0.3	0.18	0.1	0.19	0.19	0.08	42.7%
OFD2B							
OFD3B	0.3	0.27	0.15	0.26	0.25	0.07	26.8%
OFD4B	0.49	0.54	0.49	0.44	0.49	0.04	8.3%
OFD5B							
OFD6B		0.07	0.09	0.24	0.13	0.09	69.7%
OFD1C	0.21	0.16	0.18	0.17	0.18	0.02	12.0%
OFD2C							
OFD3C	0.27	0.27	0.15	0.26	0.24	0.06	24.6%
OFD4C	0.56	0.54	0.46	0.47	0.51	0.05	9.8%
OFD5C							
OFD6C	0.24	0.04	0.09	0.11	0.12	0.09	71.0%
OFD1D	0.21	0.3	0.22	0.22	0.24	0.04	17.7%
OFD2D							
OFD3D	0.24	0.24	0.15	0.24	0.22	0.04	20.7%
OFD4D	0.59	0.77	0.61	0.58	0.64	0.09	14.0%
OFD5D							
OFD6D	0.24	0.06	0.25	0.35	0.23	0.12	53.6%
OFD1E	0.64	0.68	0.8	0.55	0.67	0.10	15.5%
OFD2E							
OFD3E	0.49	0.64	0.51	0.58	0.56	0.07	12.4%
OFD4E	0.85		0.84	0.82	0.84	0.02	1.8%
OFD5E							
OFD6E	0.41	0.45	0.25	0.35	0.37	0.09	23.8%
OFD1F	0.66	0.97	0.64	0.72	0.75	0.15	20.4%
OFD2F							
OFD3F	0.41	0.54	0.51		0.49	0.07	14.0%
OFD4F	0.64	1.17	0.85	0.73	0.85	0.23	27.3%
OFD5F							
OFD6F	0.41	0.18	0.25	0.35	0.30	0.10	34.4%

Scenario 20

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir)
Fuel: JP-5

Time to Alarm from Ignition (s)						
Test	Ofd043	Ofd044	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A			0/2			
OFD2A			0/2			
OFD3A	23	23	2/2	23	0.0	0.0%
OFD4A			0/2			
OFD5A			0/2			
OFD6A	18	17	2/2	18	0.7	4.0%
OFD1B			0/2			
OFD2B			0/2			
OFD3B	42	45	2/2	44	2.1	4.9%
OFD4B			0/2			
OFD5B			0/2			
OFD6B	18	20	2/2	19	1.4	7.4%
OFD1C			0/2			
OFD2C			0/2			
OFD3C	40	44	2/2	42	2.8	6.7%
OFD4C			0/2			
OFD5C			0/2			
OFD6C	18	20	2/2	19	1.4	7.4%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	40	34	2/2	37	4.2	11.5%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	19	27	2/2	23	5.7	24.6%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	29	30	2/2	30	0.7	2.4%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	19	30	2/2	25	7.8	31.7%

Scenario 20

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir)
Fuel: JP-5

Time to Alarm from Ignition (s)						
Test	Ofd041	Ofd042	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	38	35	2/2	37	2.1	5.8%
OFD2A			0/2			
OFD3A	24	24	2/2	24	0.0	0.0%
OFD4A	67	52	2/2	60	10.6	17.8%
OFD5A			0/2			
OFD6A	21	21	2/2	21	0.0	0.0%
OFD1B		65	1/2			
OFD2B			0/2			
OFD3B	40	30	2/2	35	7.1	20.2%
OFD4B	92	88	2/2	90	2.8	3.1%
OFD5B			0/2			
OFD6B	21	21	2/2	21	0.0	0.0%
OFD1C	65	56	2/2	61	6.4	10.5%
OFD2C			0/2			
OFD3C	34	31	2/2	33	2.1	6.5%
OFD4C	93	77	2/2	85	11.3	13.3%
OFD5C			0/2			
OFD6C	21	21	2/2	21	0.0	0.0%
OFD1D			0/2			
OFD2D			0/2			
OFD3D	40	31	2/2	36	6.4	17.9%
OFD4D		98	1/2			
OFD5D			0/2			
OFD6D	27	36	2/2	32	6.4	20.2%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	30	29	2/2	30	0.7	2.4%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	54	29	2/2	42	17.7	42.6%

Scenario 20

Fuel Flow Rate: 1.7 Lpm
Scenario: Confined (y-dir)
Fuel: JP-5

Time to Alarm from Ignition (s)						
Test	Ofd040	Ofd045	Alarms/Tests	Avg.	Std. Dev.	Variance
OFD1A	43	48	2/2	46	3.5	7.8%
OFD2A			0/2			
OFD3A	27	20	2/2	24	4.9	21.1%
OFD4A	86	35	1/2	61	36.1	59.6%
OFD5A			0/2			
OFD6A	23	21	2/2	22	1.4	6.4%
OFD1B	50	41	2/2	46	6.4	14.0%
OFD2B			0/2			
OFD3B	44	31	2/2	38	9.2	24.5%
OFD4B	84		1/2			
OFD5B			0/2			
OFD6B	23	21	2/2	22	1.4	6.4%
OFD1C	48	39	2/2	44	6.4	14.6%
OFD2C			0/2			
OFD3C	44	31	2/2	38	9.2	24.5%
OFD4C	86	73	2/2	80	9.2	11.6%
OFD5C			0/2			
OFD6C	26	21	2/2	24	3.5	15.0%
OFD1D		52	1/2			
OFD2D			0/2			
OFD3D	44	26	2/2	35	12.7	36.4%
OFD4D			0/2			
OFD5D			0/2			
OFD6D	27	27	2/2	27	0.0	0.0%
OFD1E			0/2			
OFD2E			0/2			
OFD3E			0/2			
OFD4E			0/2			
OFD5E			0/2			
OFD6E	37	27	2/2	32	7.1	22.1%
OFD1F			0/2			
OFD2F			0/2			
OFD3F			0/2			
OFD4F			0/2			
OFD5F			0/2			
OFD6F	34	24	2/2	29	7.1	24.4%

Scenario 20

Fuel Flow Rate: .17 Lpm
Scenario: Confined (y-dir)
Fuel: JP-5

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd043	Ofd044	Avg.	Std. Dev.	Variance
OFD1A					
OFD2A					
OFD3A	0.04	0.04	0.04	0.00	0.0%
OFD4A					
OFD5A					
OFD6A	0.03	0.04	0.04	0.01	20.2%
OFD1B					
OFD2B					
OFD3B	0.05	0.06	0.06	0.01	12.9%
OFD4B					
OFD5B					
OFD6B	0.03	0.04	0.04	0.01	20.2%
OFD1C					
OFD2C					
OFD3C	0.05	0.06	0.06	0.01	12.9%
OFD4C					
OFD5C					
OFD6C	0.03	0.04	0.04	0.01	20.2%
OFD1D					
OFD2D					
OFD3D	0.05	0.06	0.06	0.01	12.9%
OFD4D					
OFD5D					
OFD6D	0.03	0.05	0.04	0.01	35.4%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.04	0.05	0.05	0.01	15.7%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.03	0.05	0.04	0.01	35.4%

Scenario 20

Fuel Flow Rate: .85 Lpm
Scenario: Confined (y-dir)
Fuel: JP-5

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd041	Ofd042	Avg.	Std. Dev.	Variance
OFD1A	0.09	0.11	0.10	0.01	14.1%
OFD2A					
OFD3A	0.05	0.07	0.06	0.01	23.6%
OFD4A	0.11	0.18	0.15	0.05	34.1%
OFD5A					
OFD6A	0.04	0.06	0.05	0.01	28.3%
OFD1B					
OFD2B					
OFD3B	0.09	0.10	0.10	0.01	7.4%
OFD4B	0.17	0.25	0.21	0.06	26.9%
OFD5B					
OFD6B	0.04	0.06	0.05	0.01	28.3%
OFD1C	0.10	0.18	0.14	0.06	40.4%
OFD2C					
OFD3C	0.08	0.10	0.09	0.01	15.7%
OFD4C	0.17	0.23	0.20	0.04	21.2%
OFD5C					
OFD6C	0.04	0.06	0.05	0.01	28.3%
OFD1D					
OFD2D					
OFD3D	0.09	0.10	0.10	0.01	7.4%
OFD4D			0.26		
OFD5D					
OFD6D	0.06	0.12	0.09	0.04	47.1%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.07	0.10	0.09	0.02	25.0%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.12	0.10	0.11	0.01	12.9%

Scenario 20

Fuel Flow Rate: 1.7 Lpm
Scenario: Confined (y-dir)
Fuel: JP-5

Heat Release Rates at Time of Alarm (MW)					
Test	Ofd040	Ofd045	Avg.	Std. Dev.	Variance
OFD1A	0.11	0.17	0.14	0.04	30.3%
OFD2A					
OFD3A	0.05	0.05	0.05	0.00	0.0%
OFD4A	0.23	0.12	0.18	0.08	44.4%
OFD5A					
OFD6A	0.04	0.05	0.05	0.01	15.7%
OFD1B	0.14	0.14	0.14	0.00	0.0%
OFD2B					
OFD3B	0.12	0.11	0.12	0.01	6.1%
OFD4B	84.00				
OFD5B					
OFD6B	0.04	0.05	0.05	0.01	15.7%
OFD1C	0.13	0.13	0.13	0.00	0.0%
OFD2C					
OFD3C	0.12	0.11	0.12	0.01	6.1%
OFD4C	0.23	0.20	0.22	0.02	9.9%
OFD5C					
OFD6C	0.05	0.05	0.05	0.00	0.0%
OFD1D		0.18			
OFD2D					
OFD3D	0.12	0.08	0.10	0.03	28.3%
OFD4D					
OFD5D					
OFD6D	0.05	0.09	0.07	0.03	40.4%
OFD1E					
OFD2E					
OFD3E					
OFD4E					
OFD5E					
OFD6E	0.09	0.09	0.09	0.00	0.0%
OFD1F					
OFD2F					
OFD3F					
OFD4F					
OFD5F					
OFD6F	0.08	0.07	0.08	0.01	9.4%

Scenario 21

Time to Alarm from Ignition (s)

Scenario: Pan Fire
Pan Size: 0.3 x 0.3 m
Fuel: Gasoline

Test	Ofd109
OFD1A	
OFD2A	
OFD3A	8
OFD4A	
OFD5A	
OFD6A	9
OFD1B	
OFD2B	
OFD3B	
OFD4B	
OFD5B	
OFD6B	12
OFD1C	
OFD2C	
OFD3C	
OFD4C	
OFD5C	
OFD6C	15
OFD1D	
OFD2D	
OFD3D	24
OFD4D	
OFD5D	
OFD6D	24
OFD1E	
OFD2E	
OFD3E	
OFD4E	
OFD5E	
OFD6E	18
OFD1F	
OFD2F	
OFD3F	
OFD4F	
OFD5F	
OFD6F	13

Scenario: Pan Fire
Pan Size: 0.6 x 0.6 m
Fuel: Gasoline

Test	Ofd014
OFD1A	4
OFD2A	
OFD3A	2
OFD4A	6
OFD5A	3
OFD6A	5
OFD1B	4
OFD2B	
OFD3B	3
OFD4B	6
OFD5B	
OFD6B	8
OFD1C	5
OFD2C	
OFD3C	4
OFD4C	6
OFD5C	
OFD6C	8
OFD1D	4
OFD2D	
OFD3D	2
OFD4D	6
OFD5D	25
OFD6D	10
OFD1E	10
OFD2E	
OFD3E	4
OFD4E	17
OFD5E	
OFD6E	9
OFD1F	17
OFD2F	
OFD3F	4
OFD4F	17
OFD5F	
OFD6F	6

Scenario: Pan Fire
Pan Size: 0.91 m dia.
Fuel: Gasoline

Test	Ofd016
OFD1A	4
OFD2A	13
OFD3A	6
OFD4A	5
OFD5A	5
OFD6A	8
OFD1B	4
OFD2B	
OFD3B	6
OFD4B	6
OFD5B	
OFD6B	8
OFD1C	5
OFD2C	
OFD3C	6
OFD4C	6
OFD5C	
OFD6C	128
OFD1D	5
OFD2D	
OFD3D	4
OFD4D	6
OFD5D	34
OFD6D	8
OFD1E	14
OFD2E	
OFD3E	5
OFD4E	12
OFD5E	
OFD6E	7
OFD1F	11
OFD2F	
OFD3F	6
OFD4F	6
OFD5F	
OFD6F	250

Scenario 21

Scenario: Pan Fire
Pan Size: 0.6 x 0.6 m
Fuel: Gasoline

HRR at Alarm Time (MW)	
Test	Ofd014
OFD1A	0.25
OFD2A	
OFD3A	0.18
OFD4A	0.3
OFD5A	0.21
OFD6A	0.27
OFD1B	0.25
OFD2B	
OFD3B	0.21
OFD4B	0.3
OFD5B	
OFD6B	0.35
OFD1C	0.27
OFD2C	
OFD3C	0.25
OFD4C	0.3
OFD5C	
OFD6C	0.35
OFD1D	0.25
OFD2D	
OFD3D	0.18
OFD4D	0.3
OFD5D	0.48
OFD6D	0.38
OFD1E	0.38
OFD2E	
OFD3E	0.25
OFD4E	0.4
OFD5E	
OFD6E	0.36
OFD1F	0.4
OFD2F	
OFD3F	0.25
OFD4F	0.4
OFD5F	
OFD6F	0.3

Scenario: Pan Fire
Pan Size: 0.91 m dia.
Fuel: Gasoline

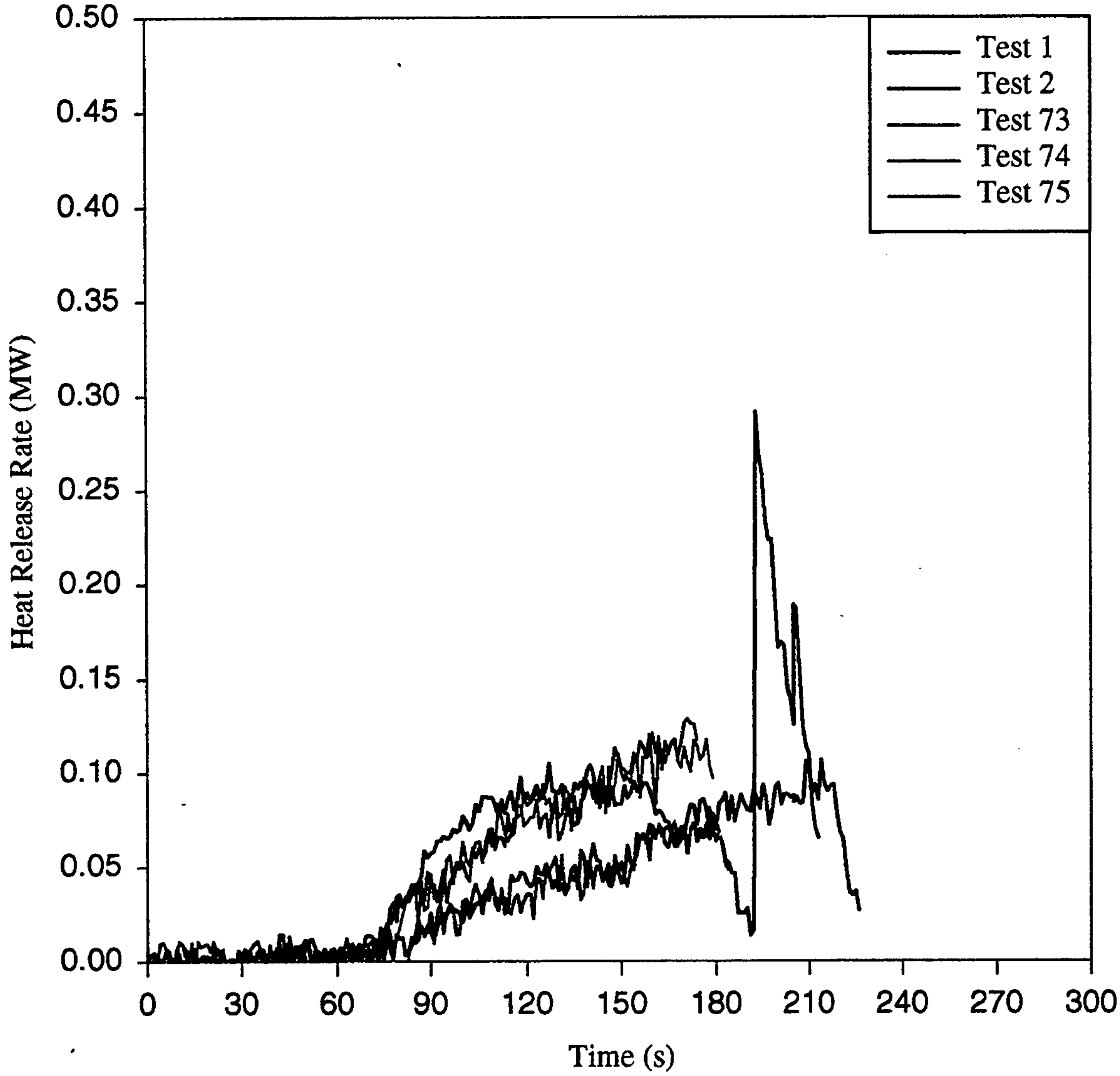
HRR at Alarm Time (MW)	
Test	Ofd016
OFD1A	0.43
OFD2A	0.88
OFD3A	0.63
OFD4A	0.5
OFD5A	0.5
OFD6A	0.78
OFD1B	0.43
OFD2B	
OFD3B	0.63
OFD4B	0.63
OFD5B	
OFD6B	0.78
OFD1C	0.5
OFD2C	
OFD3C	0.63
OFD4C	0.63
OFD5C	1.07
OFD6C	0.5
OFD1D	5
OFD2D	
OFD3D	0.43
OFD4D	0.63
OFD5D	1.02
OFD6D	0.78
OFD1E	0.91
OFD2E	
OFD3E	0.5
OFD4E	0.85
OFD5E	
OFD6E	0.69
OFD1F	0.83
OFD2F	
OFD3F	0.63
OFD4F	0.63
OFD5F	
OFD6F	

Appendix D

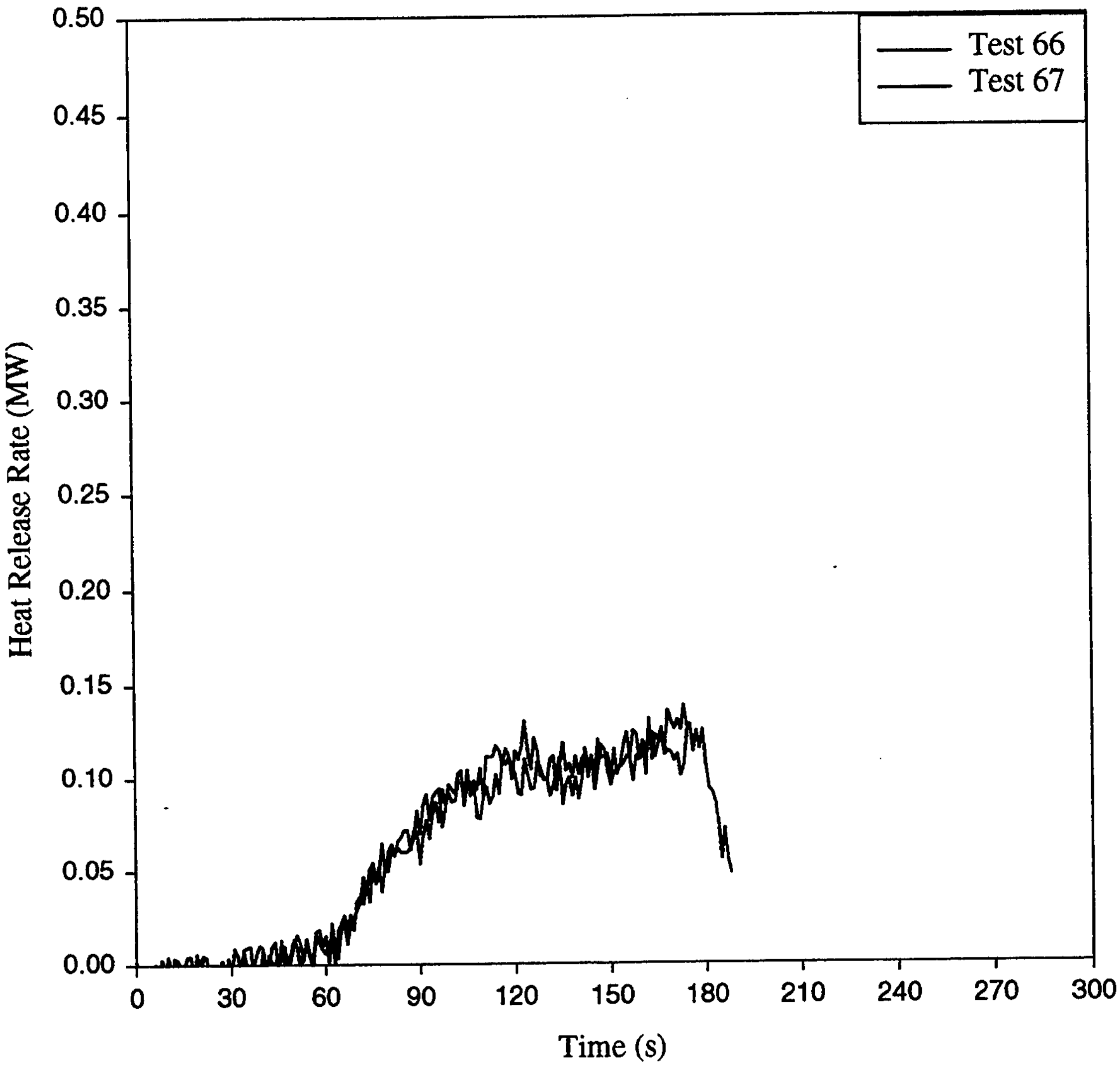
Heat Release Rate Plots

This appendix contains heat release rate (HRR) plots for each test scenario. The plots are grouped according to the columns in Table 5 of the report, such that all test scenarios for the same fuel and fire type are together.

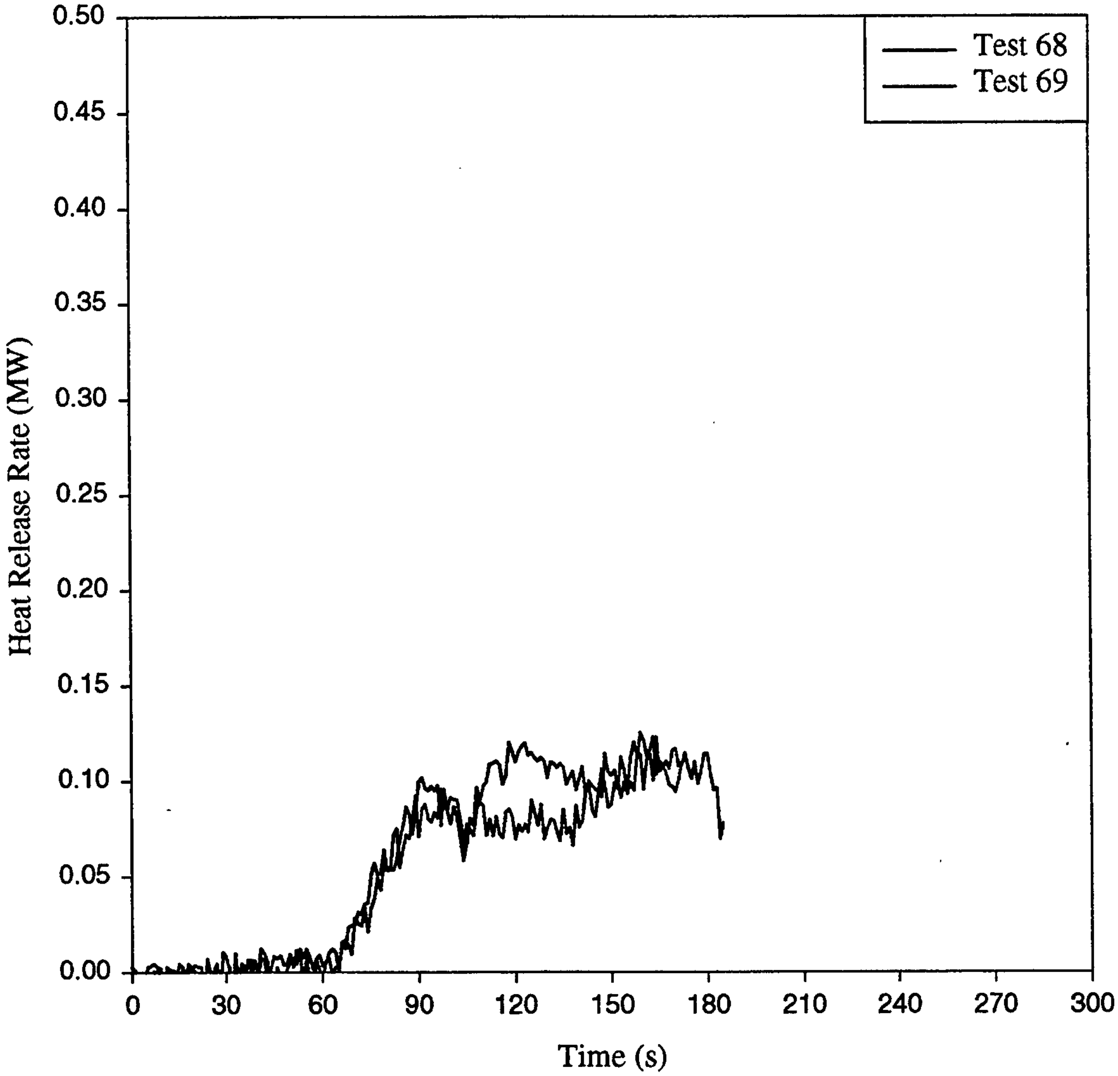
Appendix D Contents



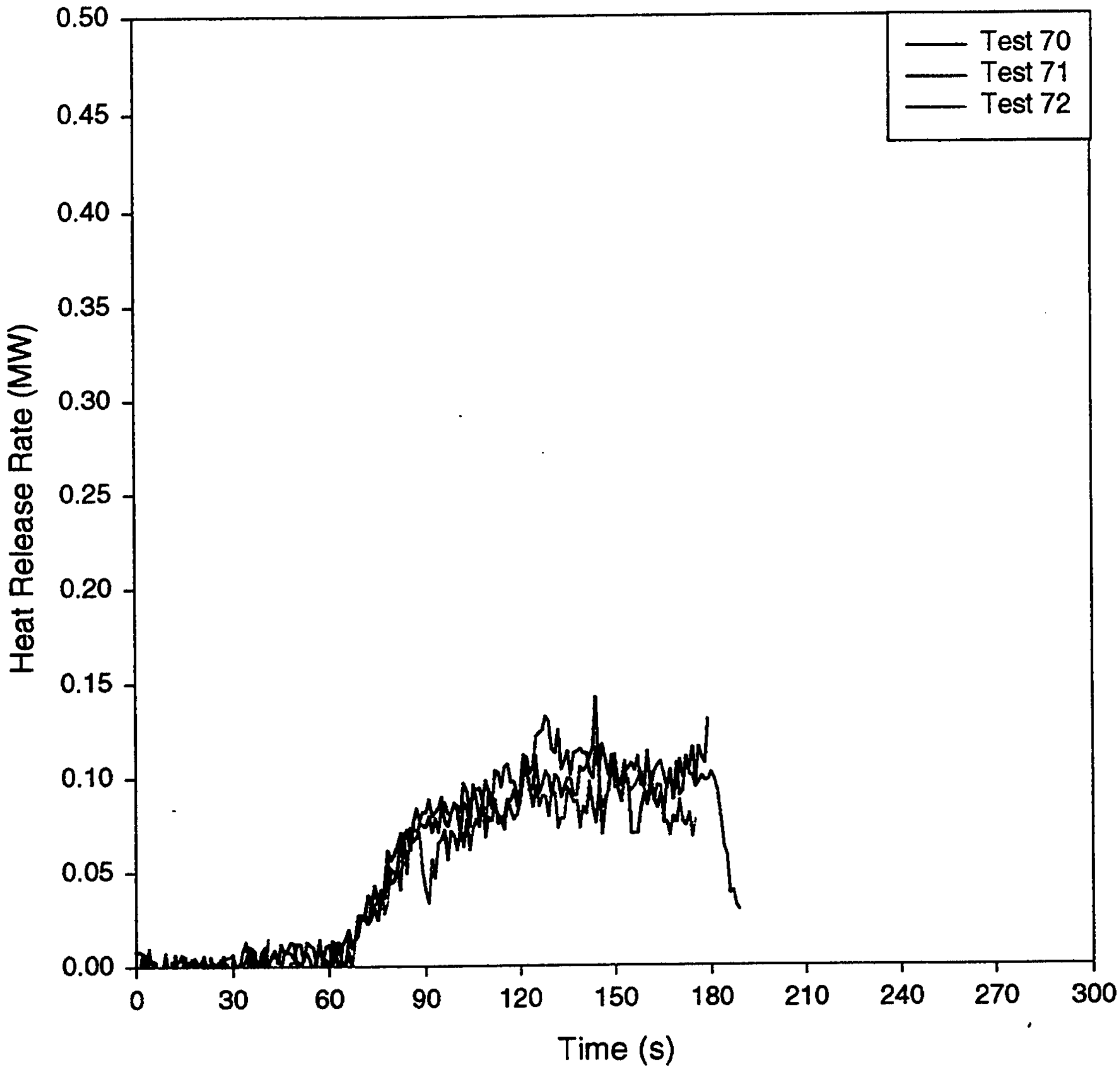
Comparison of heat release rates for .17 Lpm unconfined spill fires.



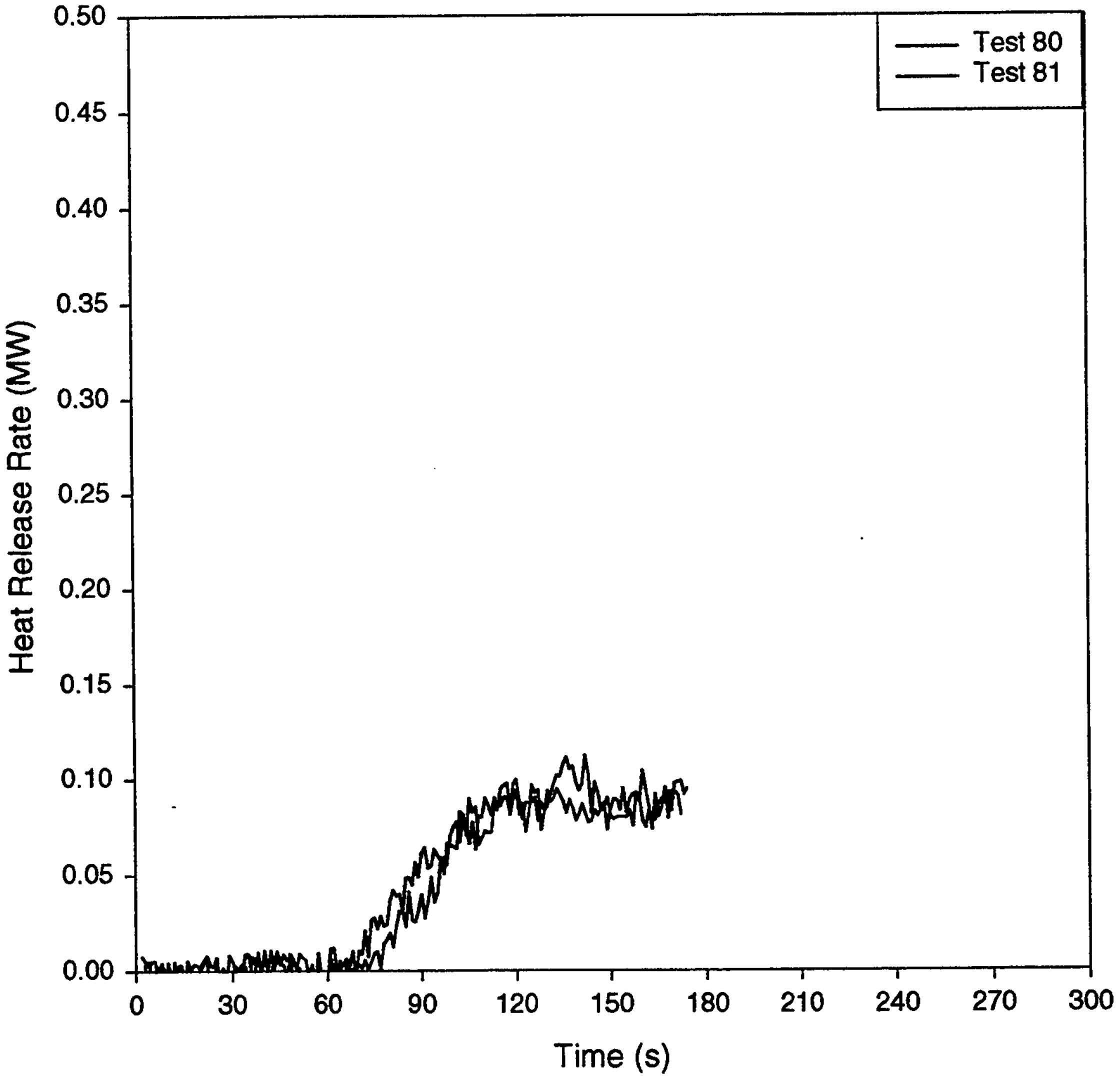
Comparison of heat release rates for .17 Lpm unconfined spill fires with chopped UV/IR.



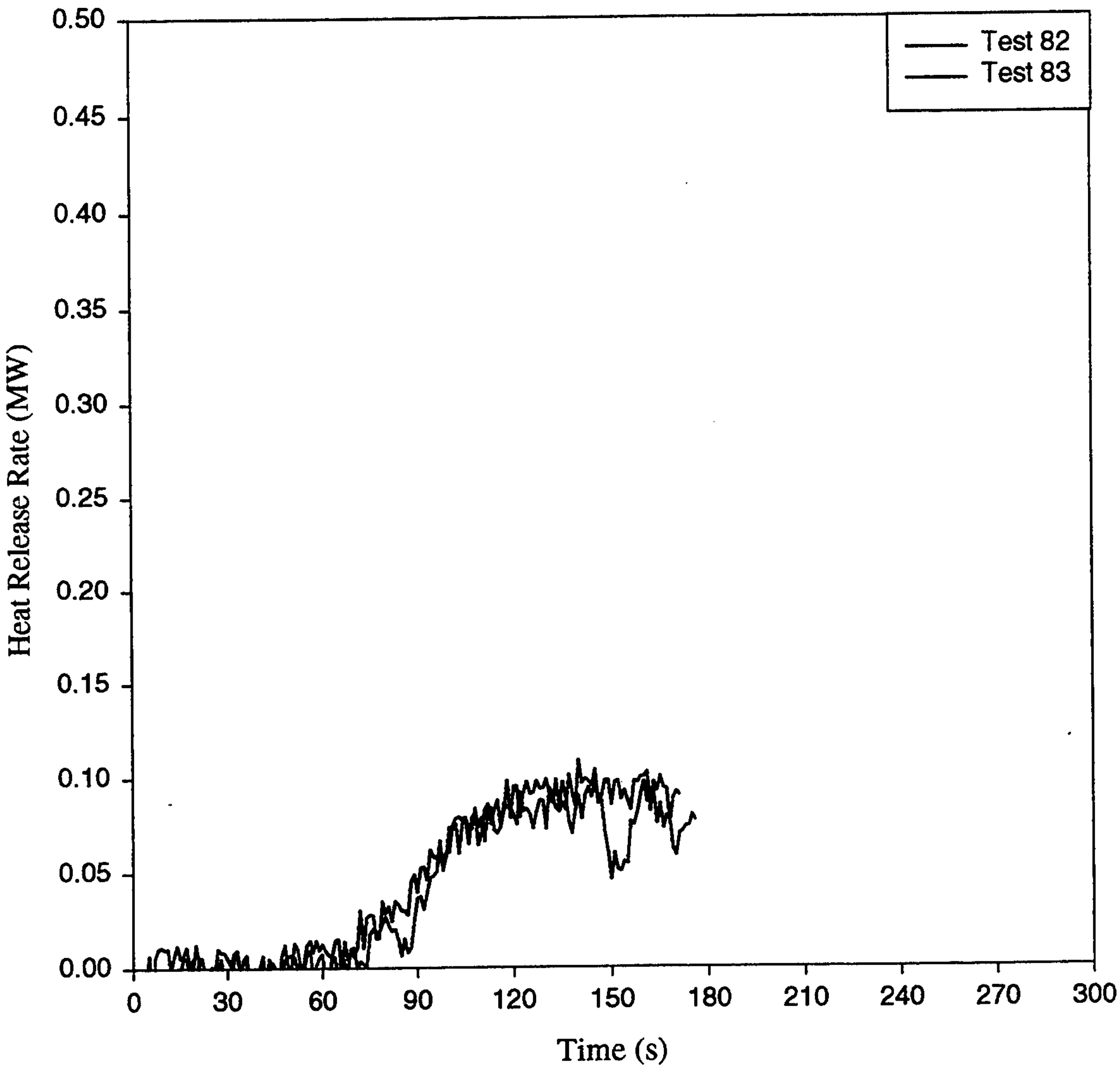
Comparison of heat release rates for .17 Lpm
unconfined spill fires with chopped IR at 20 m.



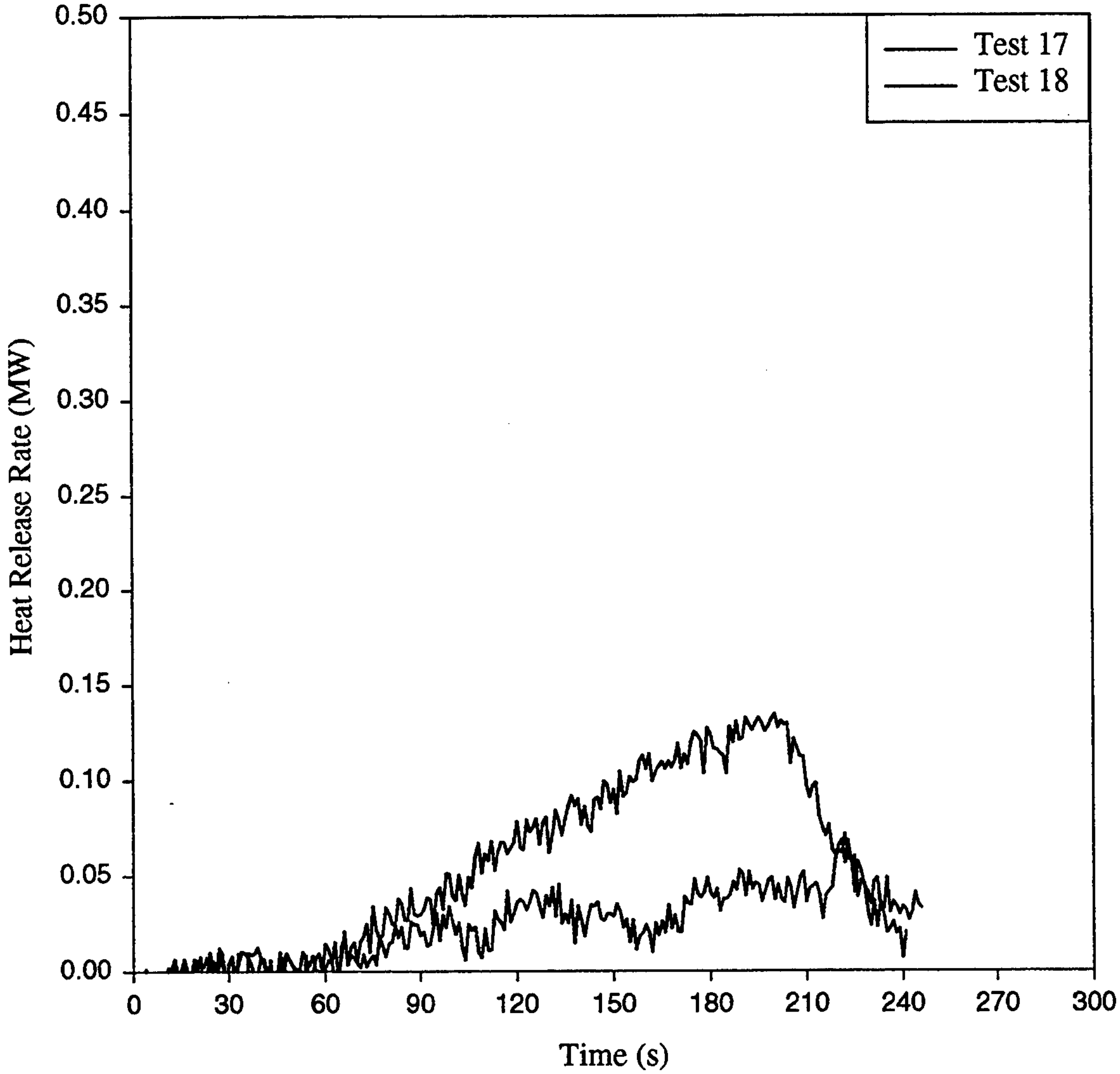
Comparison of heat release rates for .17 unconfined spill fires with chopped IR at 26 m.



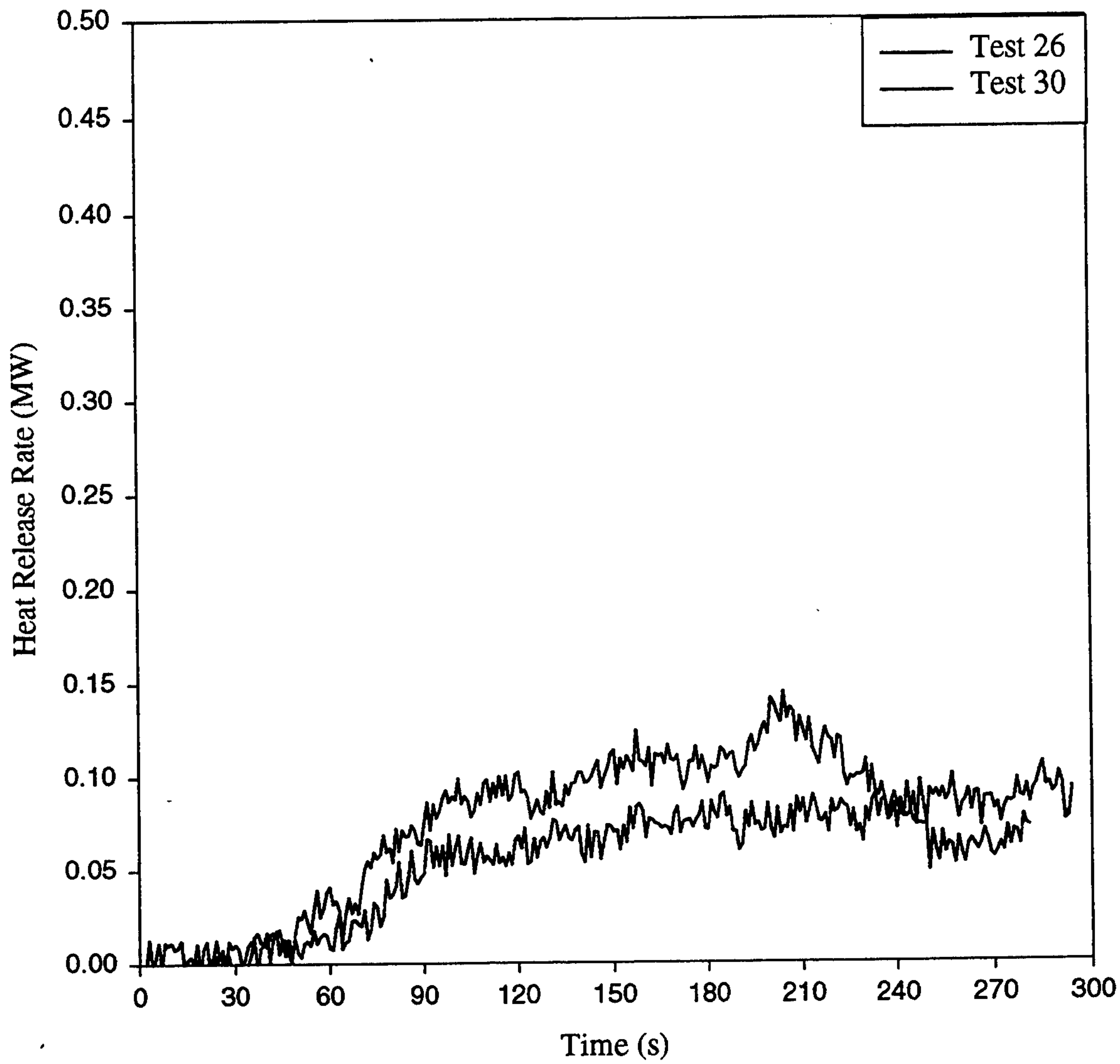
Comparison of heat release rates for .17 Lpm unconfined spill fires with arc welding at 15 m.



Comparison of heat release rates for .17 Lpm unconfined spill fires with doors open and lights on.



Comparison of heat release rates for .17 Lpm
confined in the x-direction spill fires.



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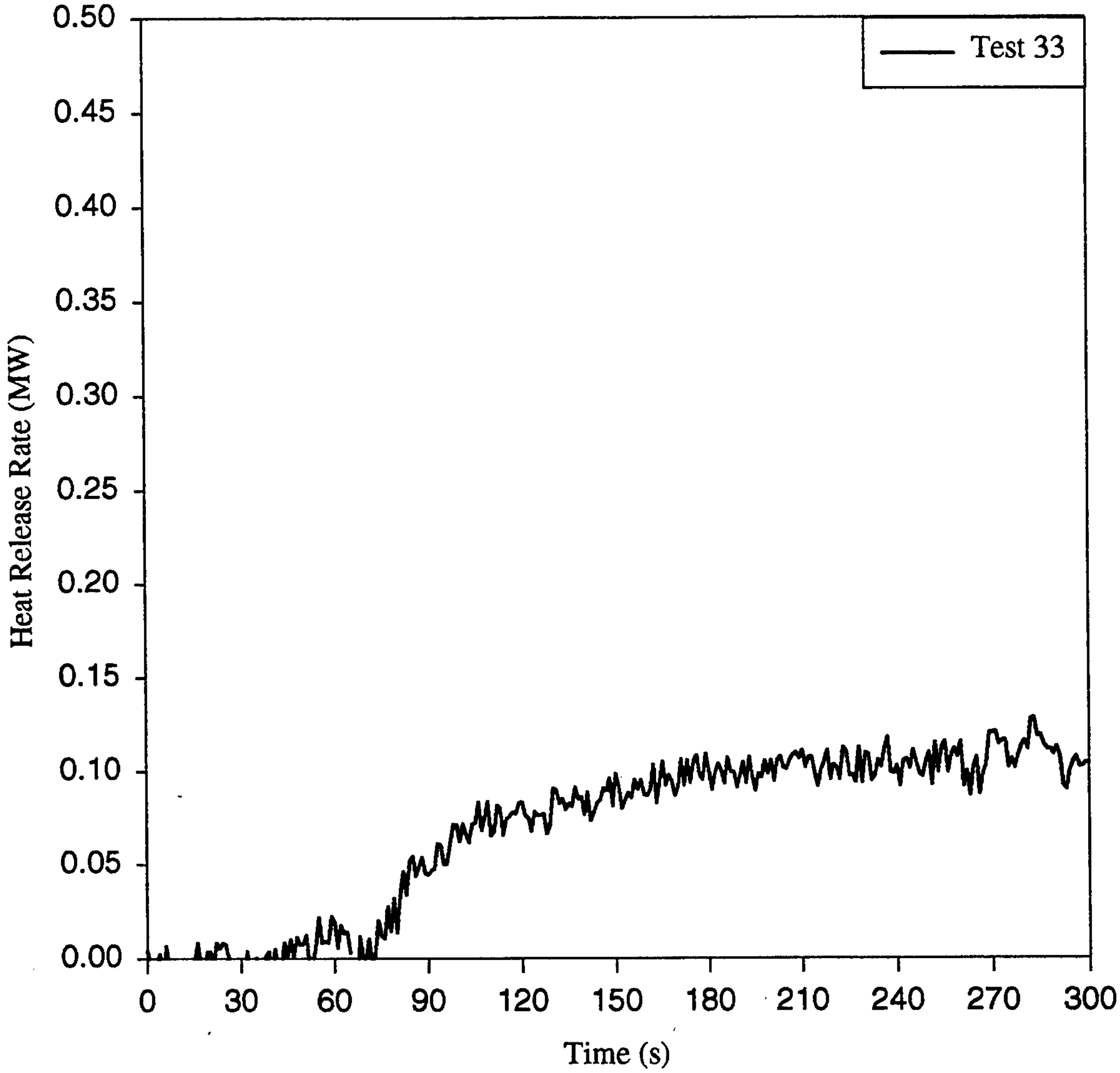
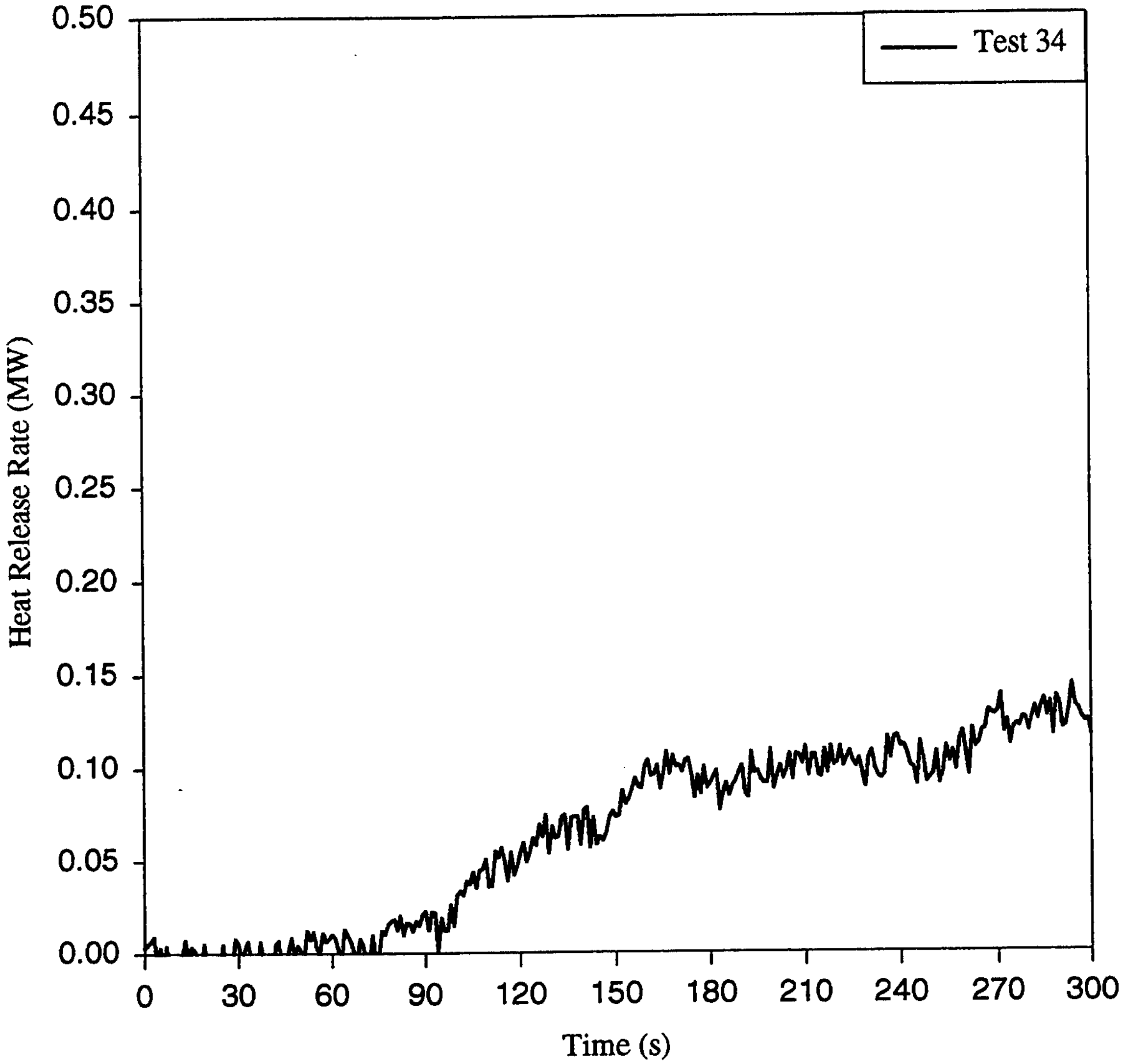
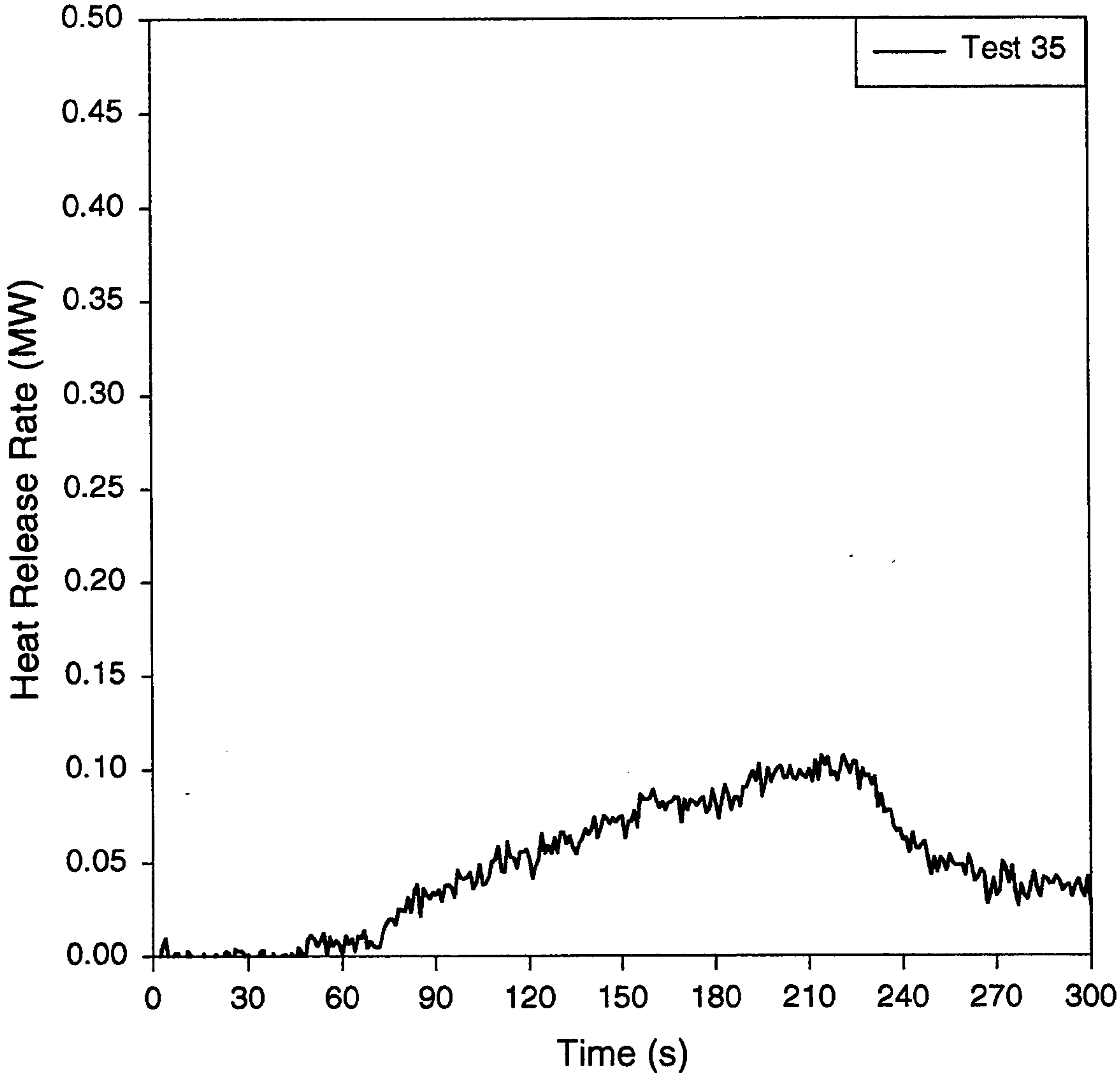


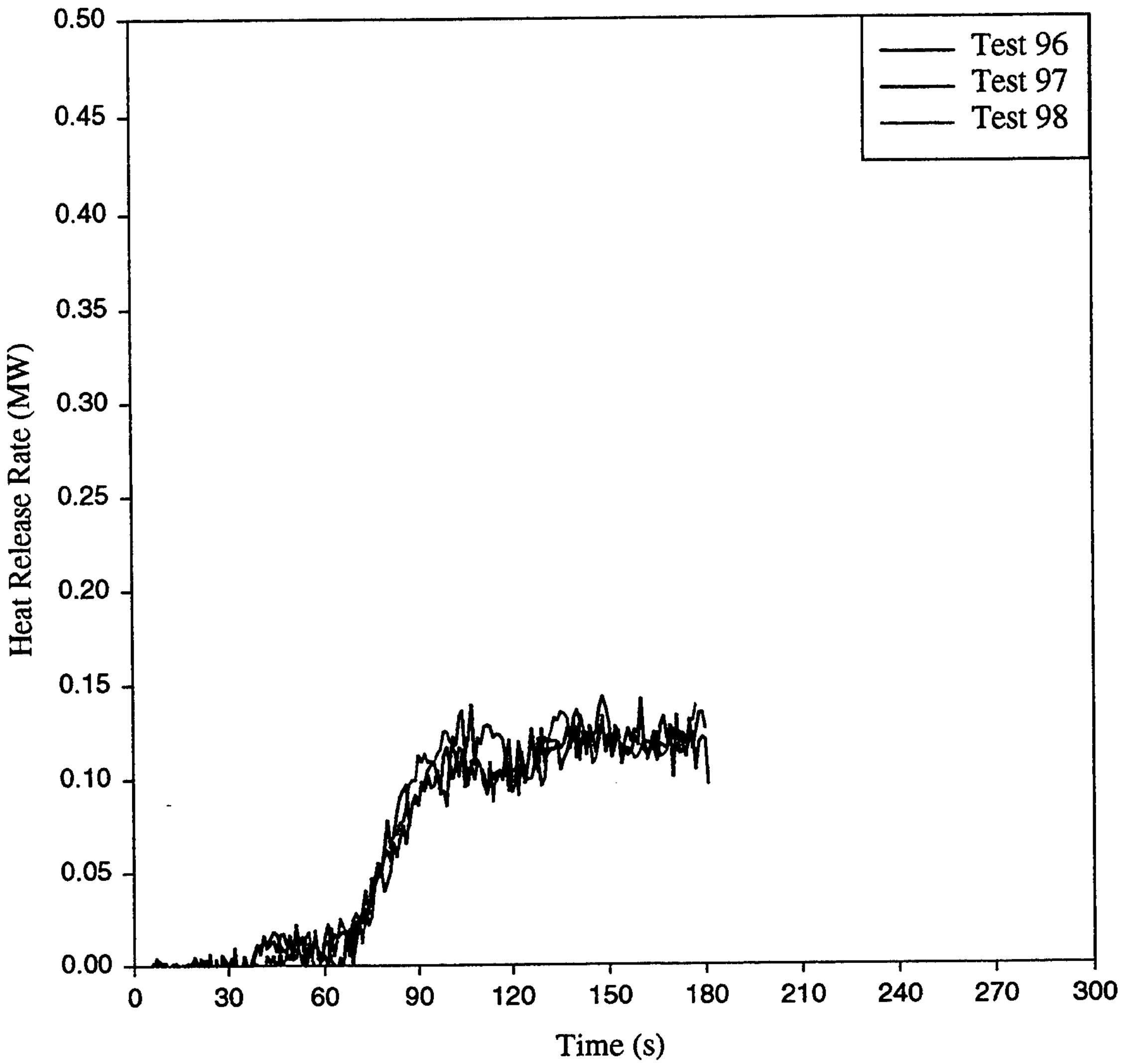
Heat release rate for .17 Lpm confined in the y-direction spill fire with chopped UV/IR.



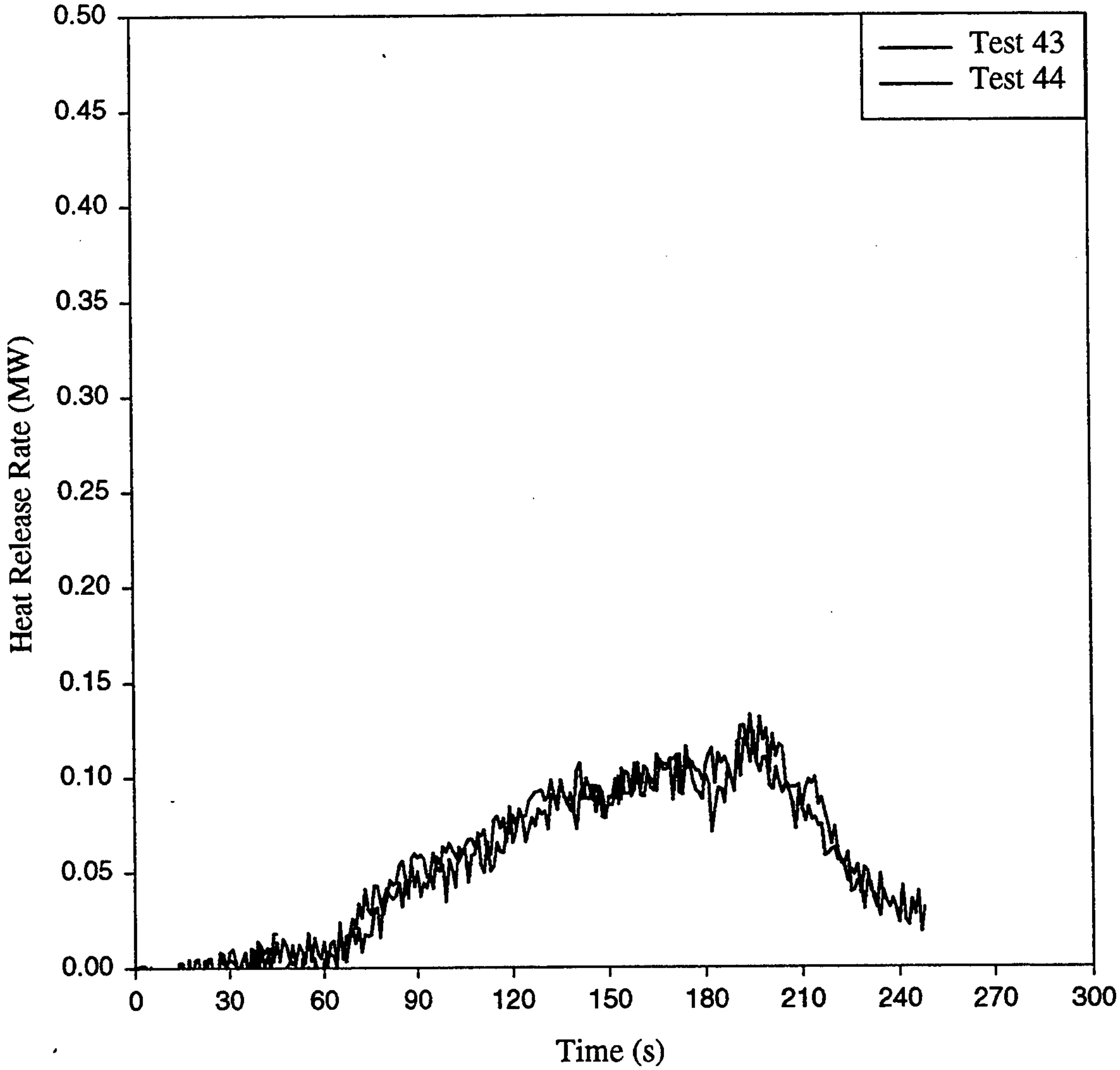
Heat release rate for .17 Lpm confined in the y-direction spill fire with chopped IR at 20 m.



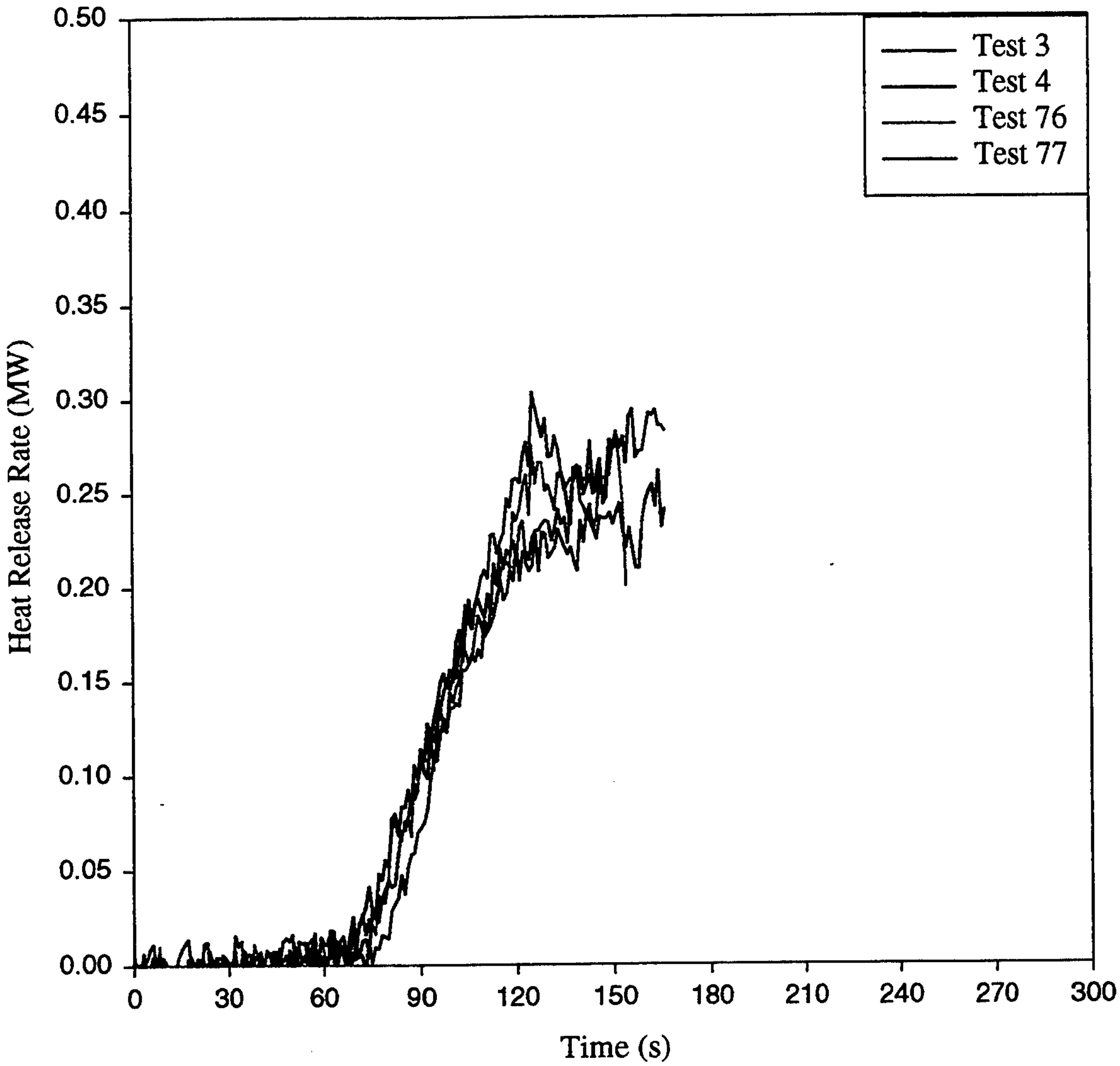
Heat release rate for .17 Lpm confined in the
y-direction spill fire with chopped IR at 26 m.



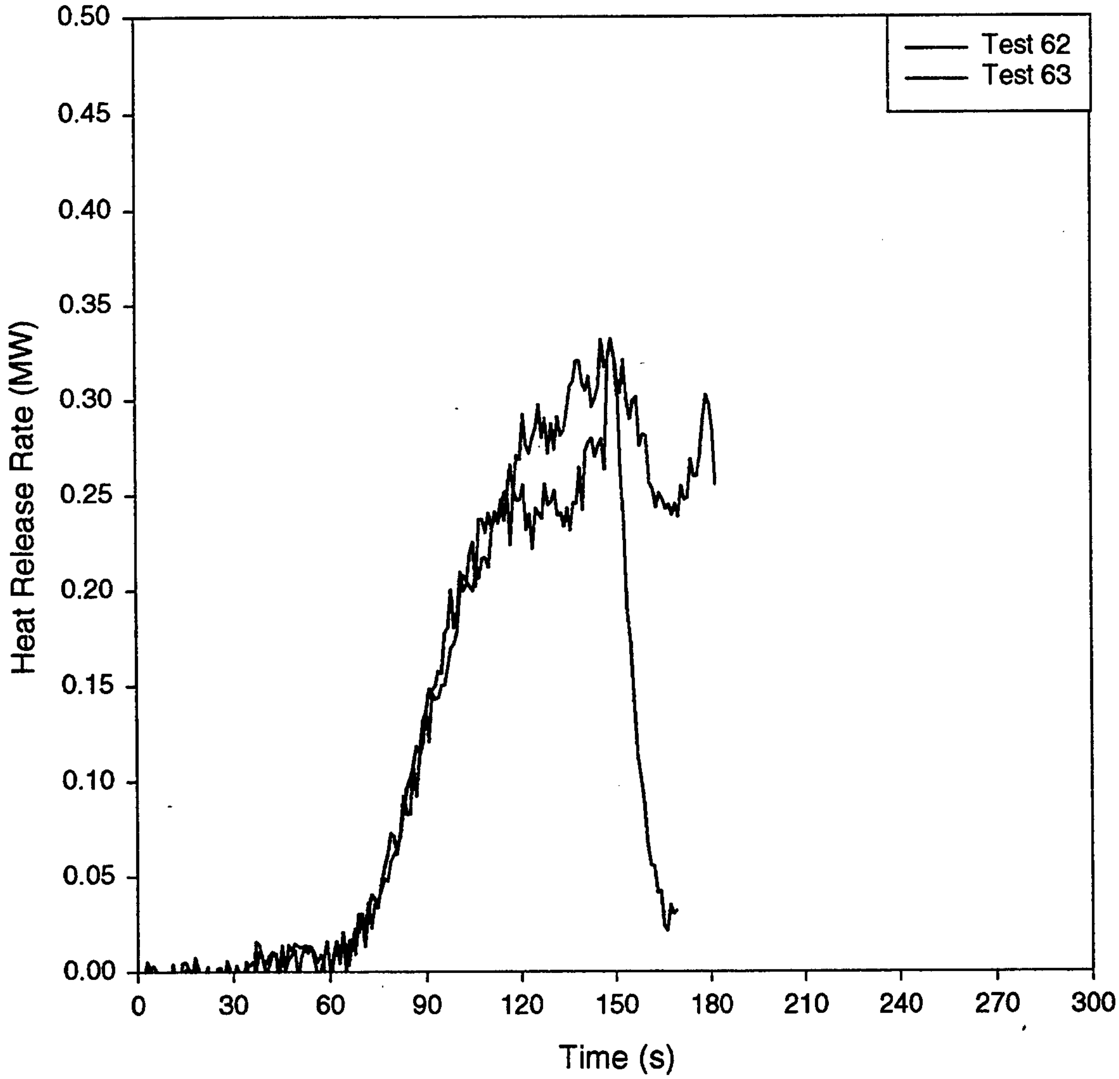
Comparison of heat release rates for .17 Lpm
unconfined spill fires using JP-5.



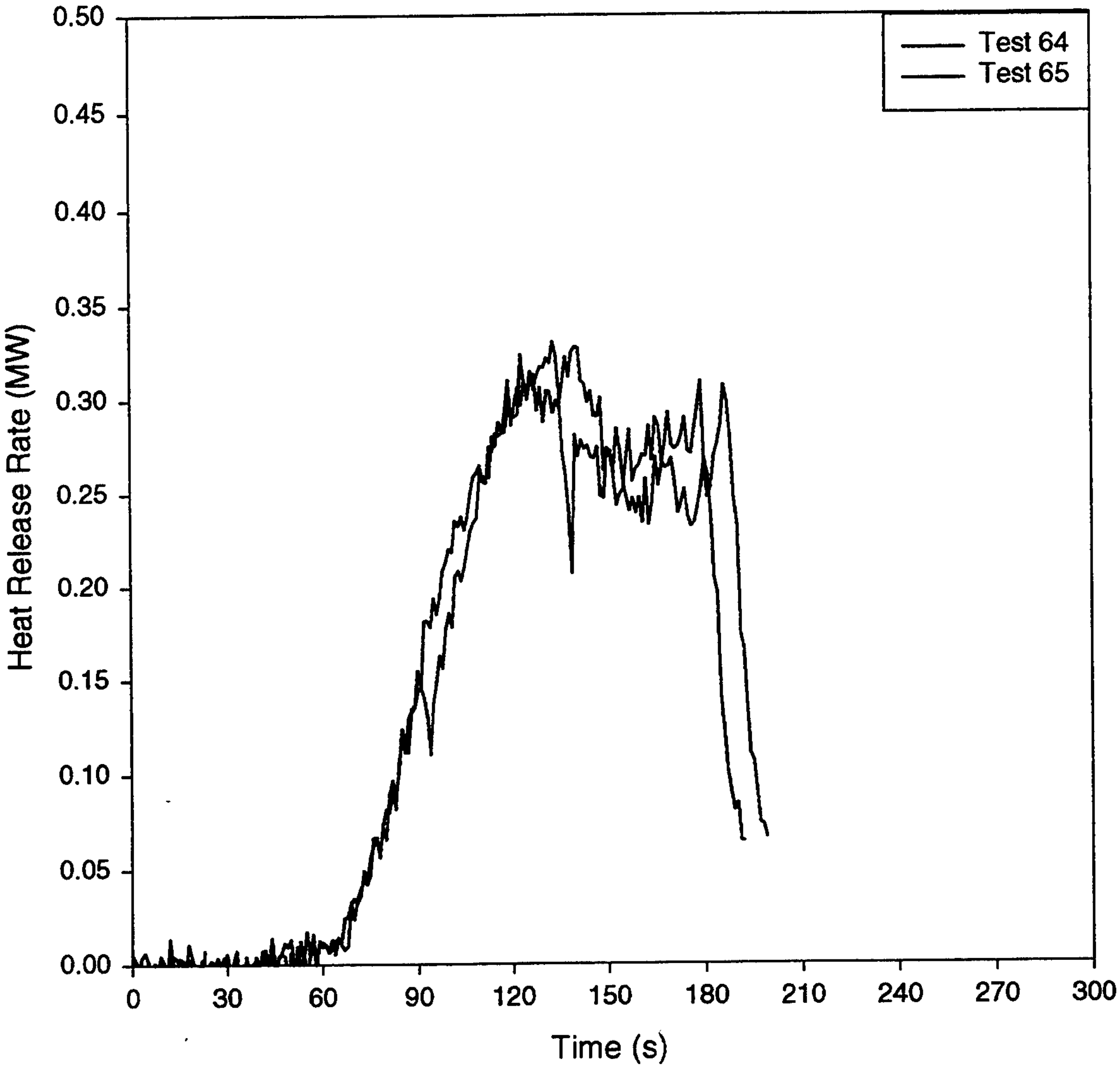
Comparison heat release rates for .17 Lpm confined
in the y-direction spill fires using JP-5.



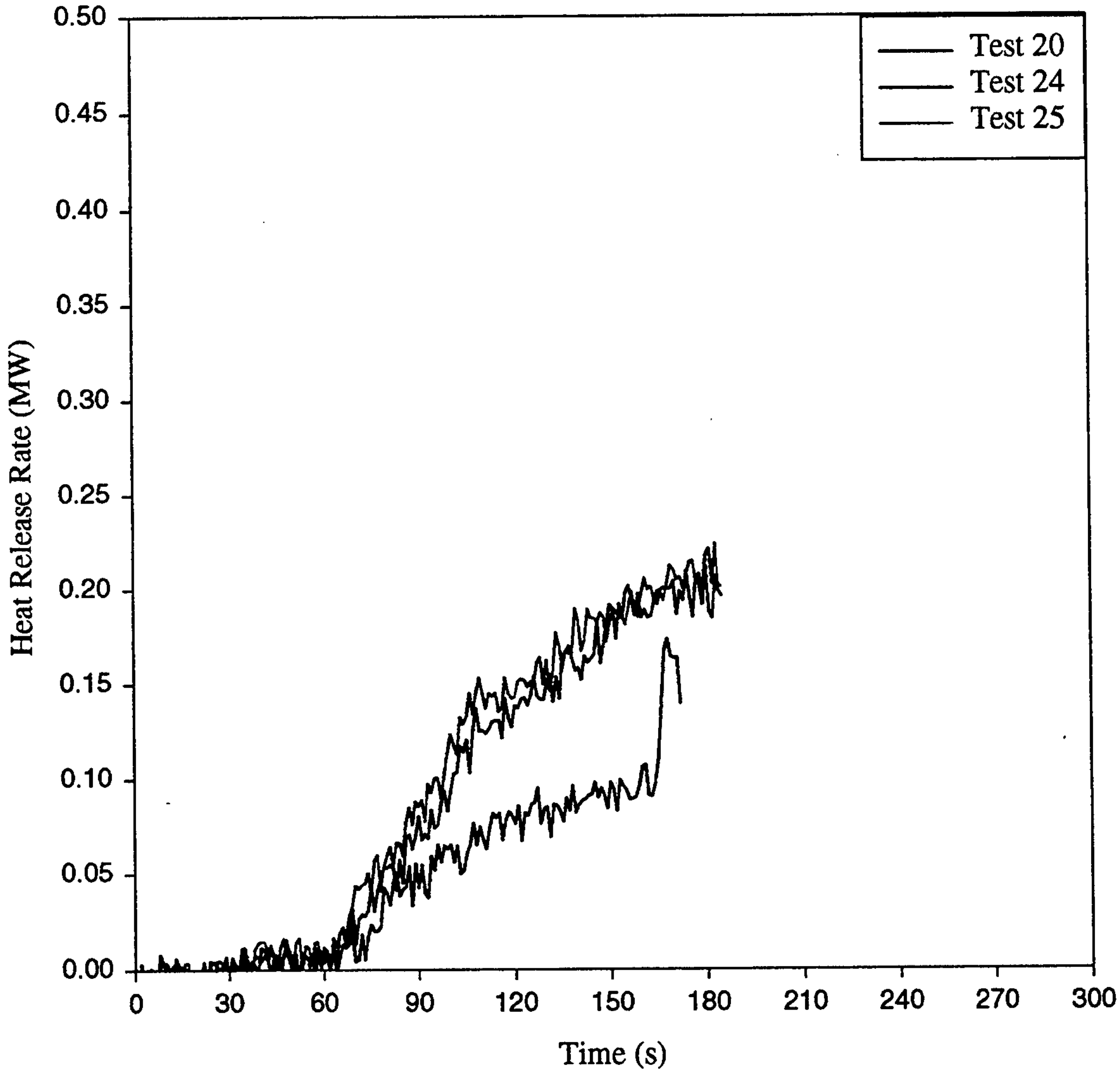
Comparison of heat release rates for .42 Lpm unconfined spill fires.



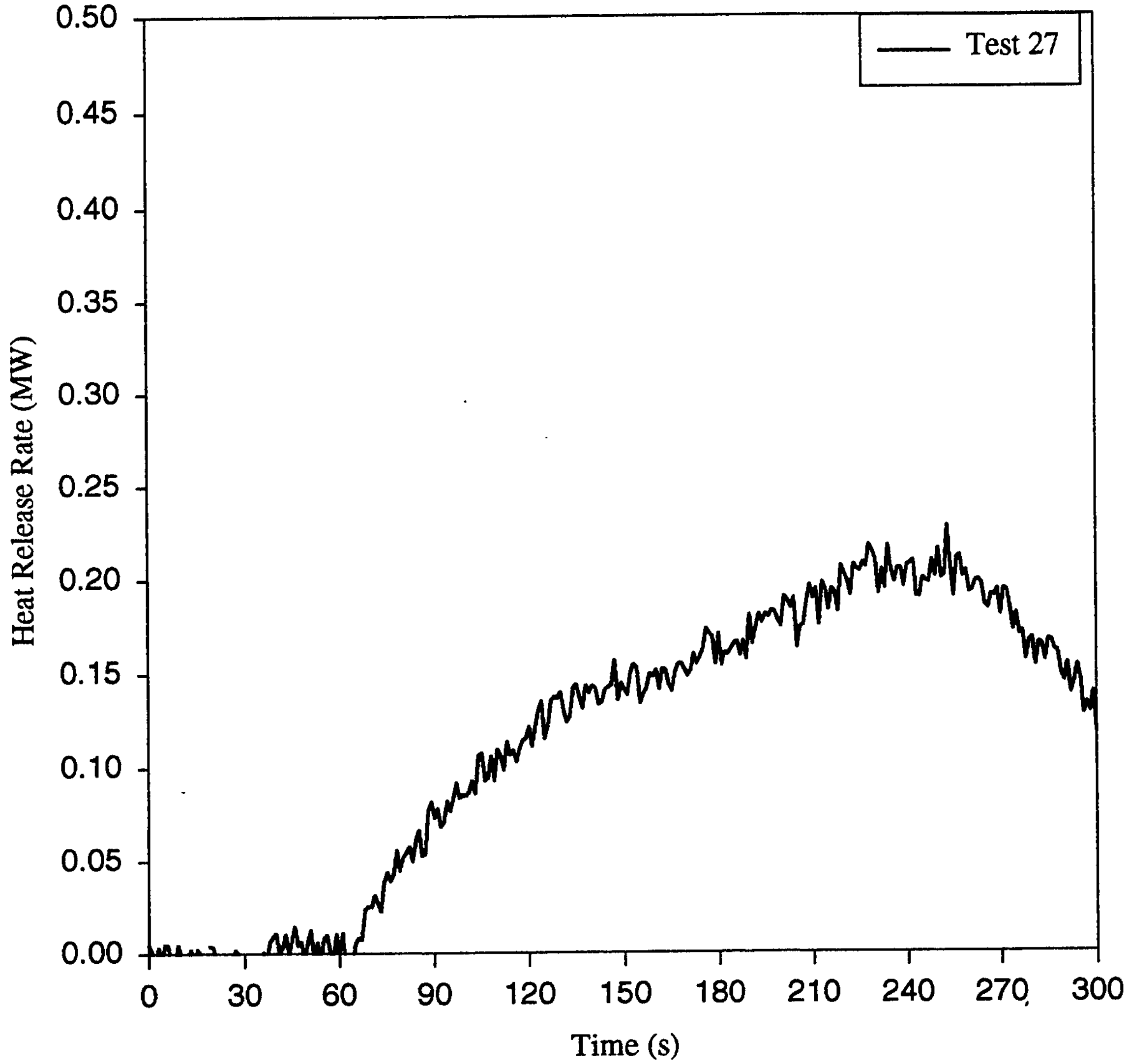
Comparison of heat release rates for .42 Lpm unconfined spill fires with an obstruction .3-2.3 m in height.



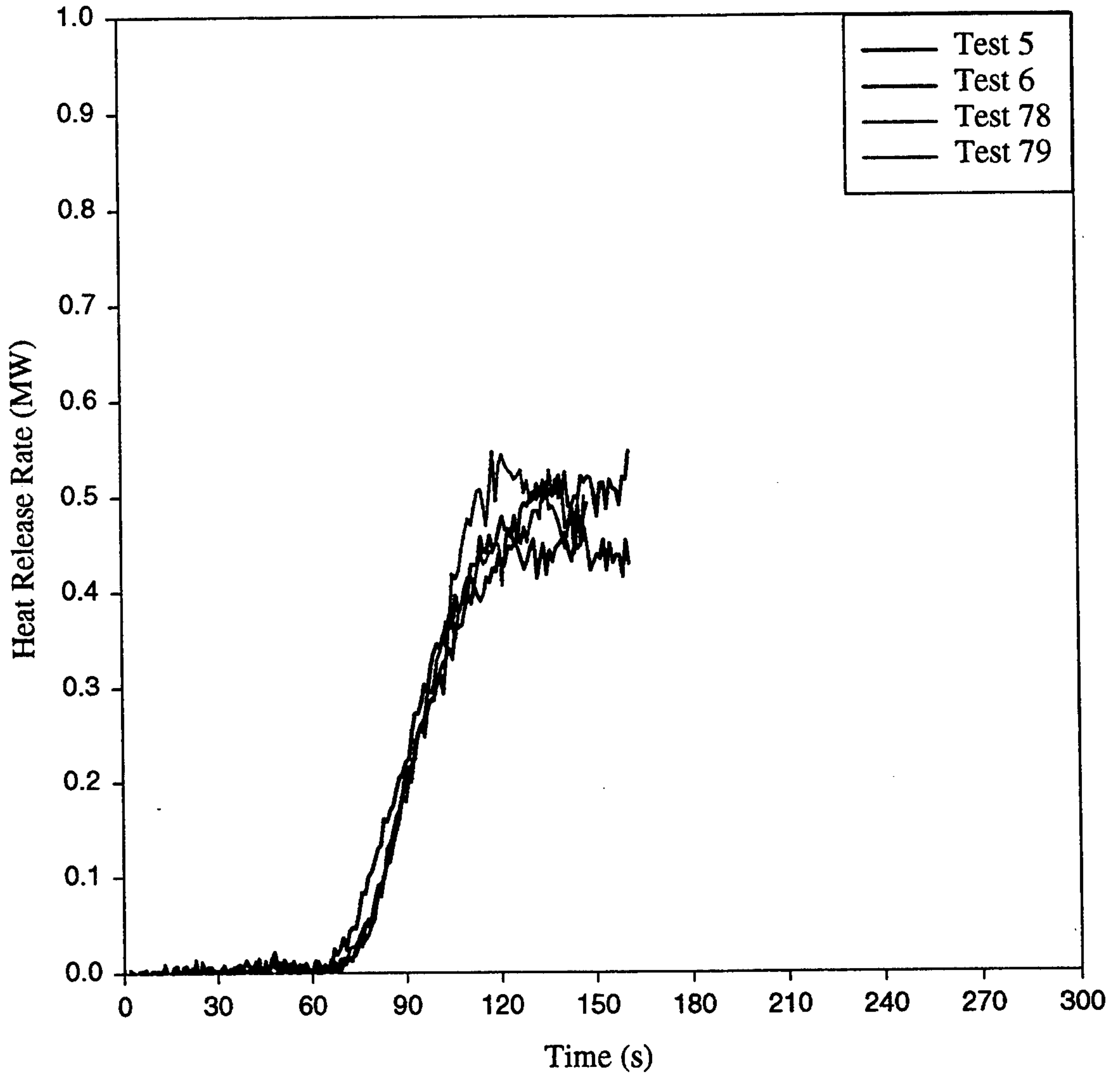
Comparison of heat release rates for .42 Lpm unconfined spill fires with a moving obstruction .3-2.3 m in height.



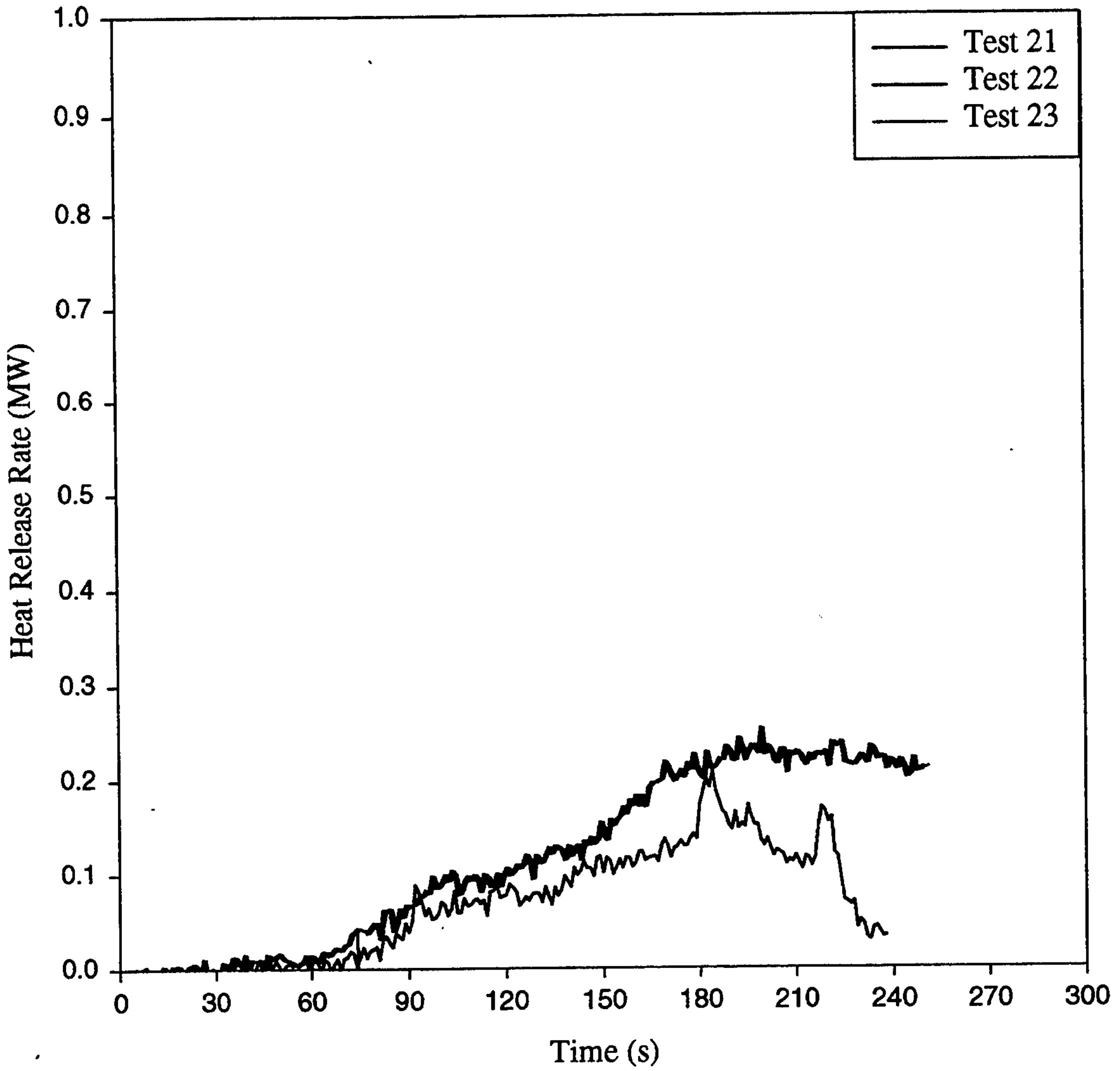
Comparison of heat release rates for 0.42 Lpm JP-8 spill fires confined in the x-direction.



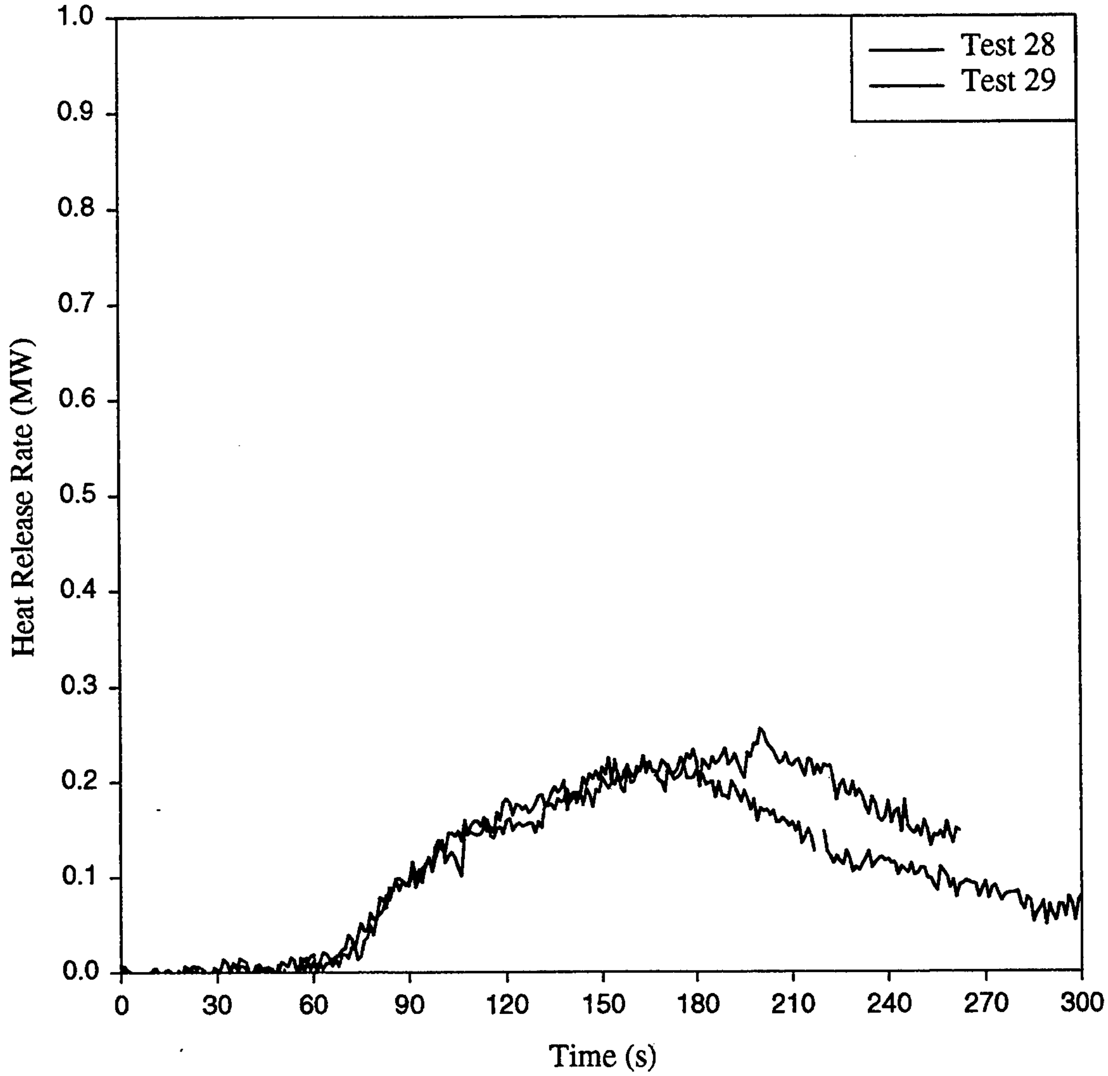
Heat release rate for .42 Lpm confined in the y-direction spill fire.



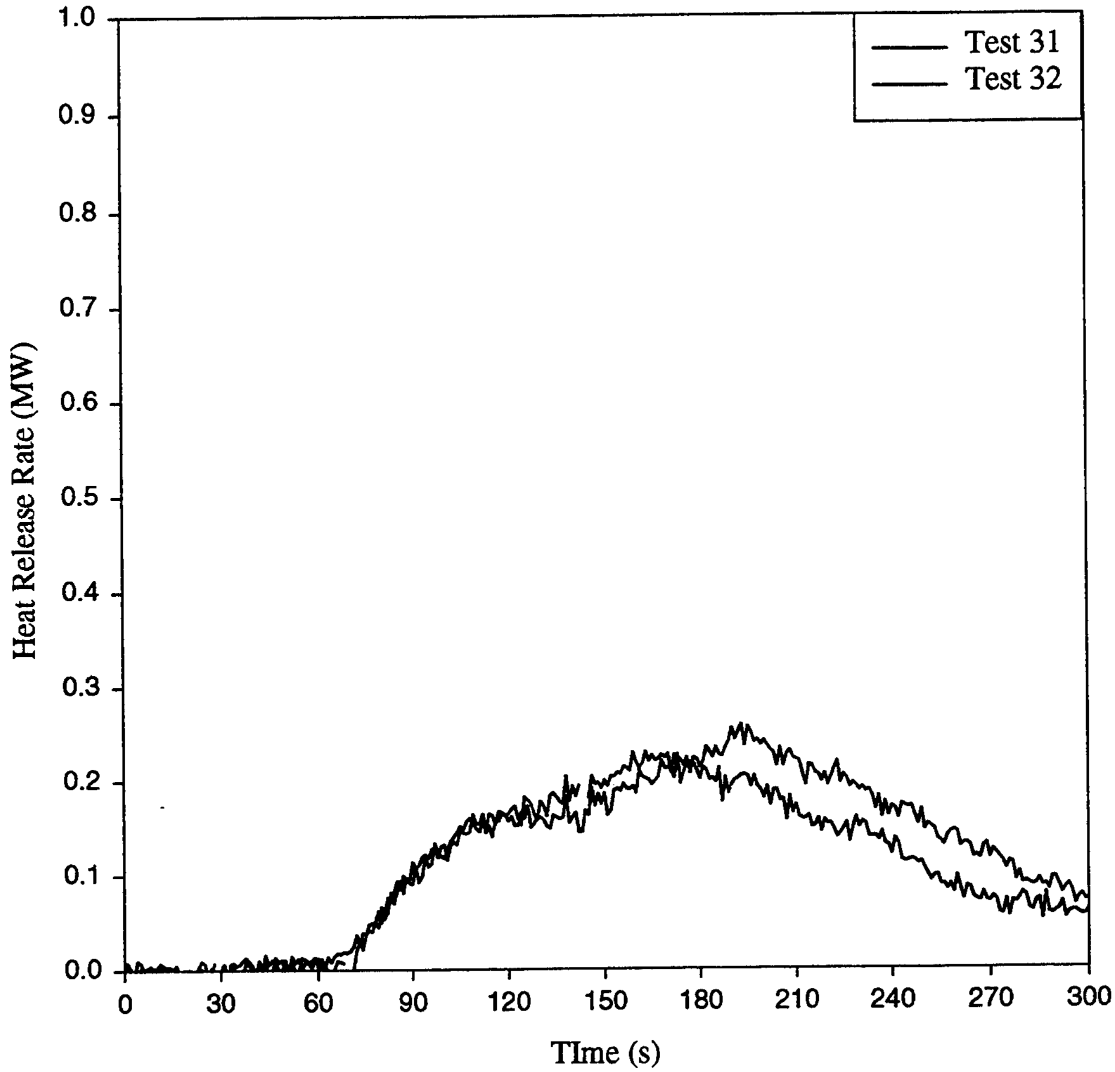
Comparison heat release rates for .85 Lpm unconfined spill fires.



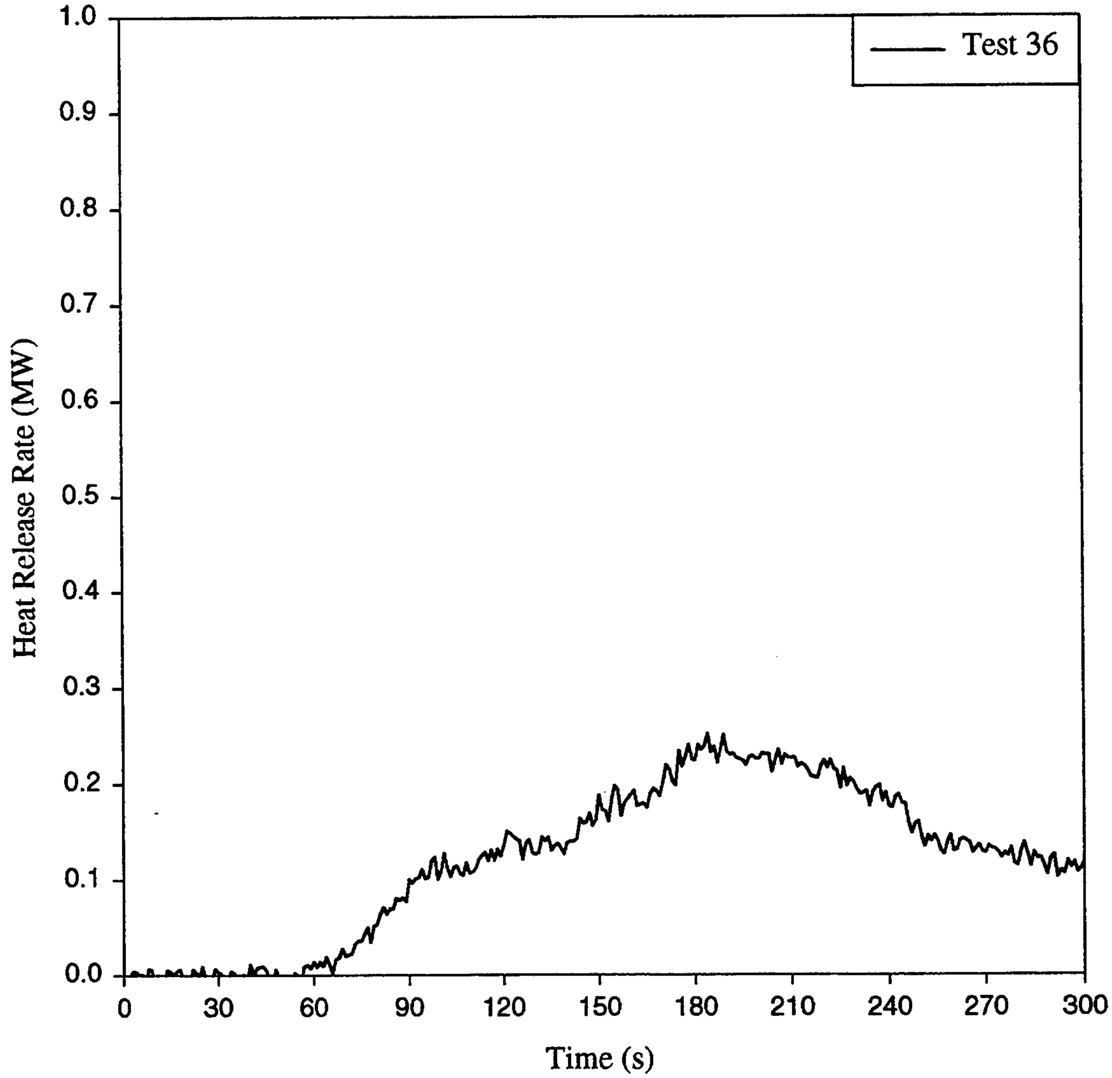
Comparison of heat release rates for .85 Lpm
for confined in the x-direction spill fires.



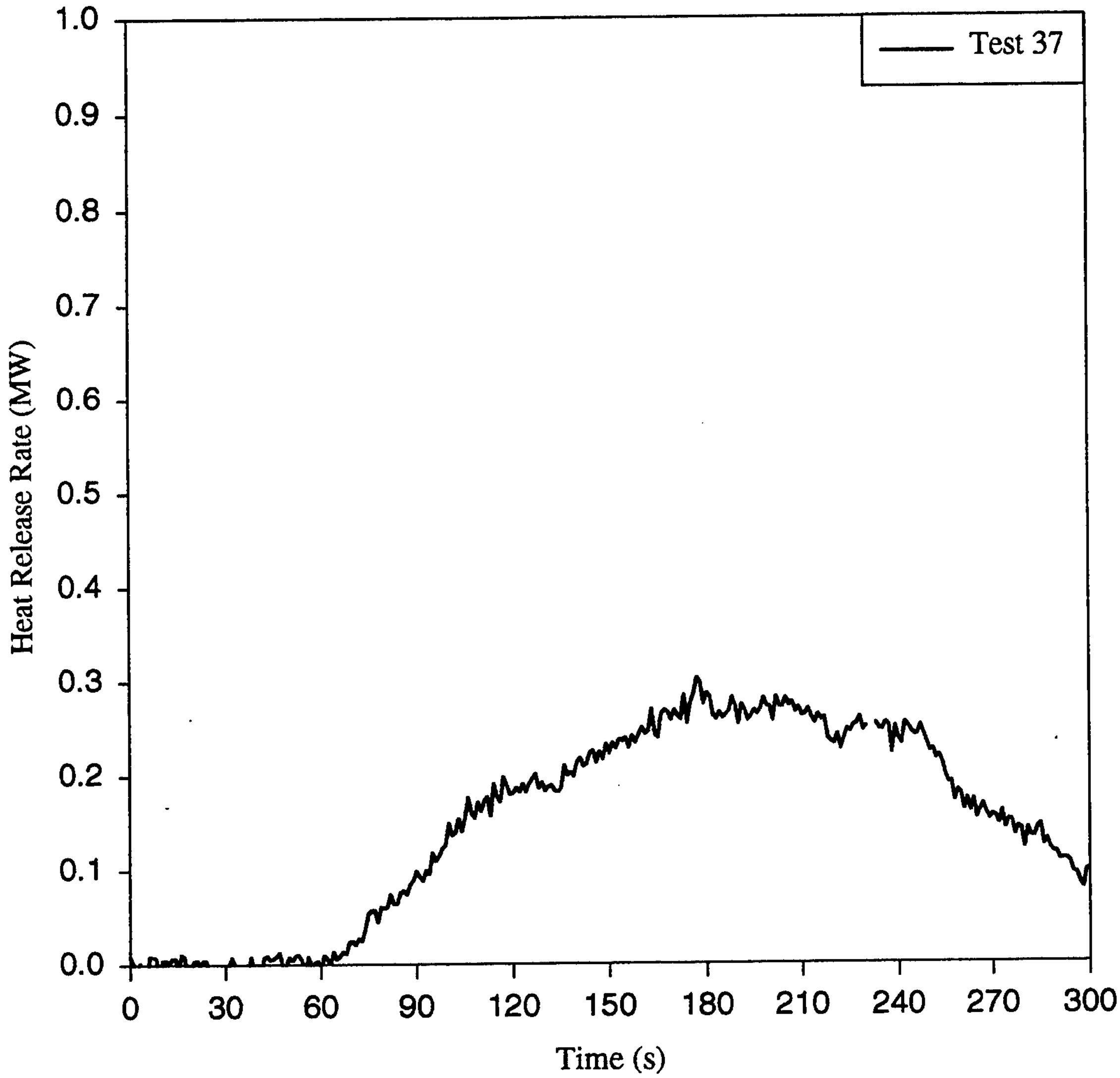
Comparison of heat release rates for .85 Lpm
confined in the y-direction spill fires.



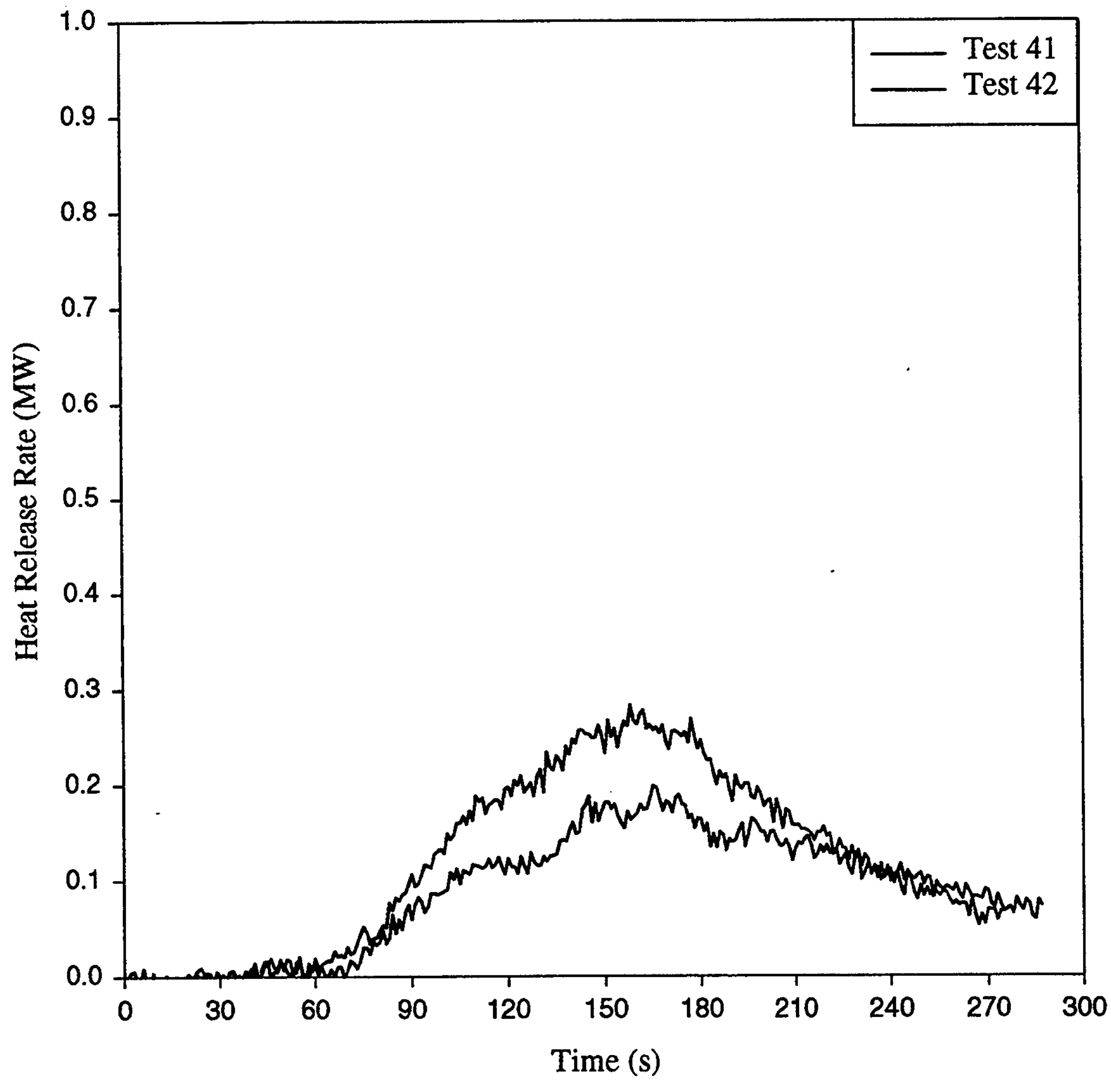
Comparison of heat release rates for.85 Lpm confined
in the y-direction spill fires with chopped UV/IR.



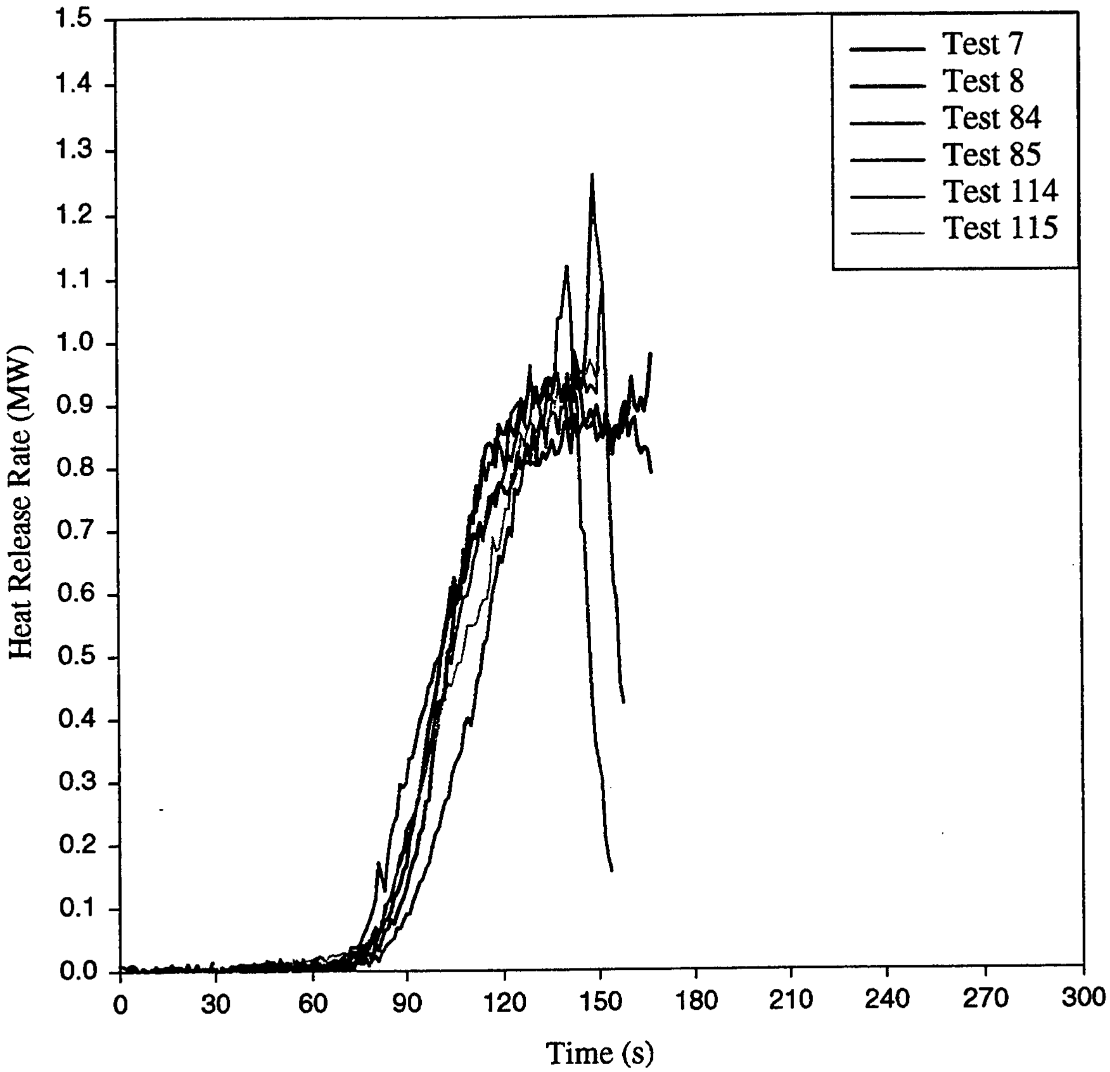
Heat release rate for .85 Lpm confined in the y-direction spill fire with chopped IR at 20 m.



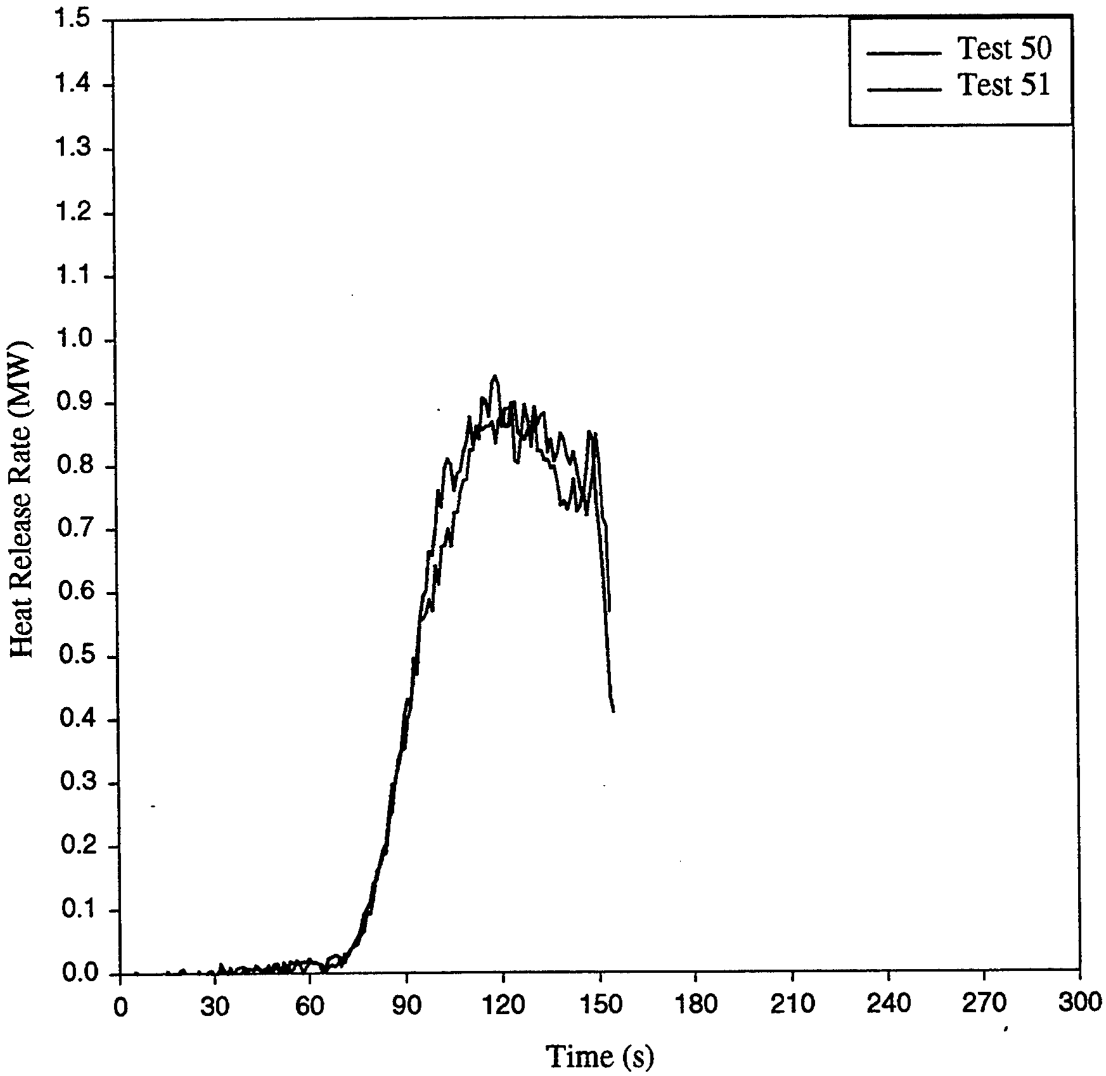
Heat release rate for .85 Lpm confined in the y-direction spill fire with chopped IR at 26 m.



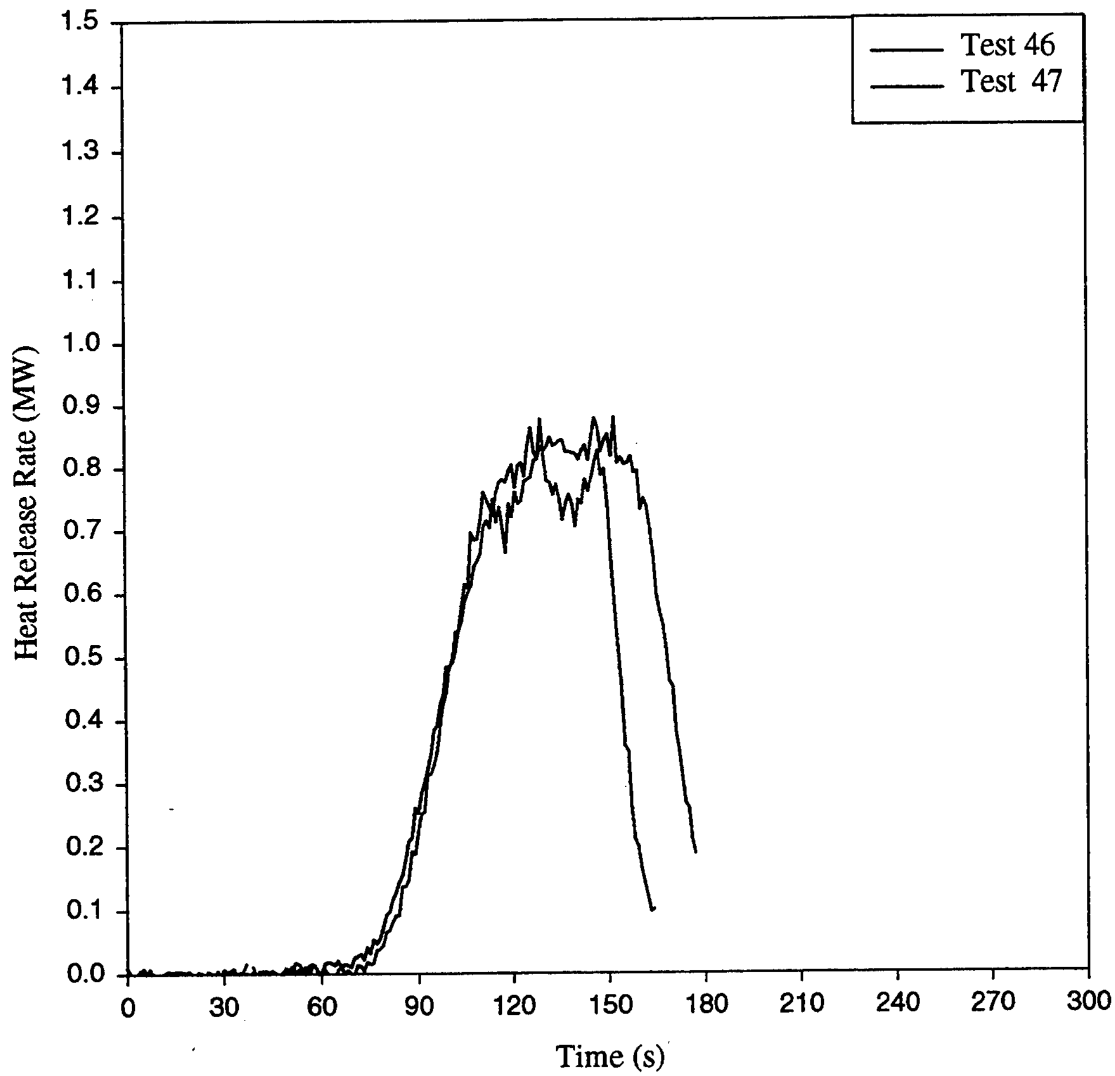
Comparison of heat release rates for .85 Lpm confined in the y-direction spill fires using JP-5.



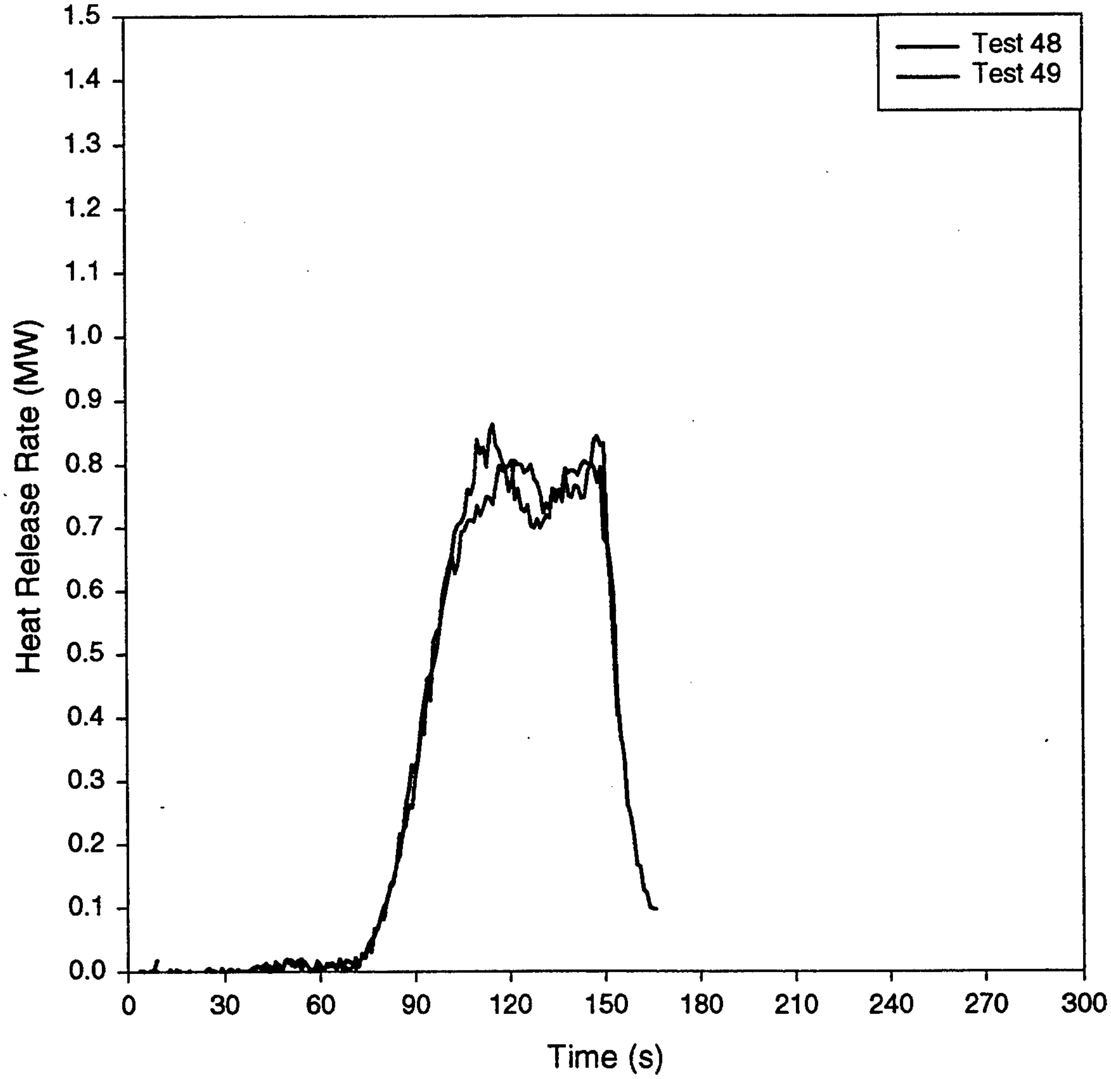
Comparison of heat release rates for Scenario 1, 1.7 Lpm unconfined JP-8 spill fires.



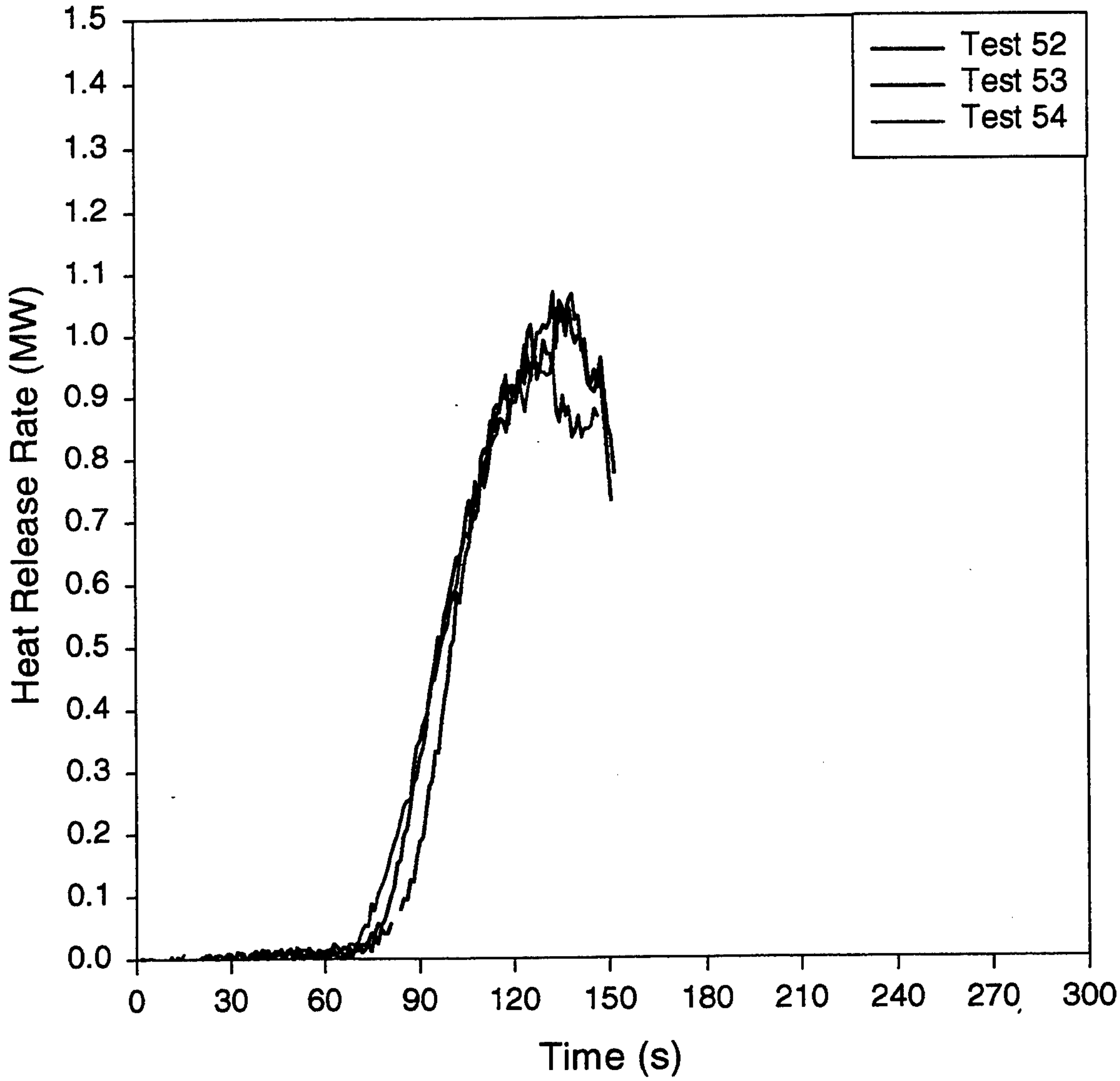
Comparison of heat release rates for 1.7 Lpm
unconfined spill fires with chopped UV/IR.



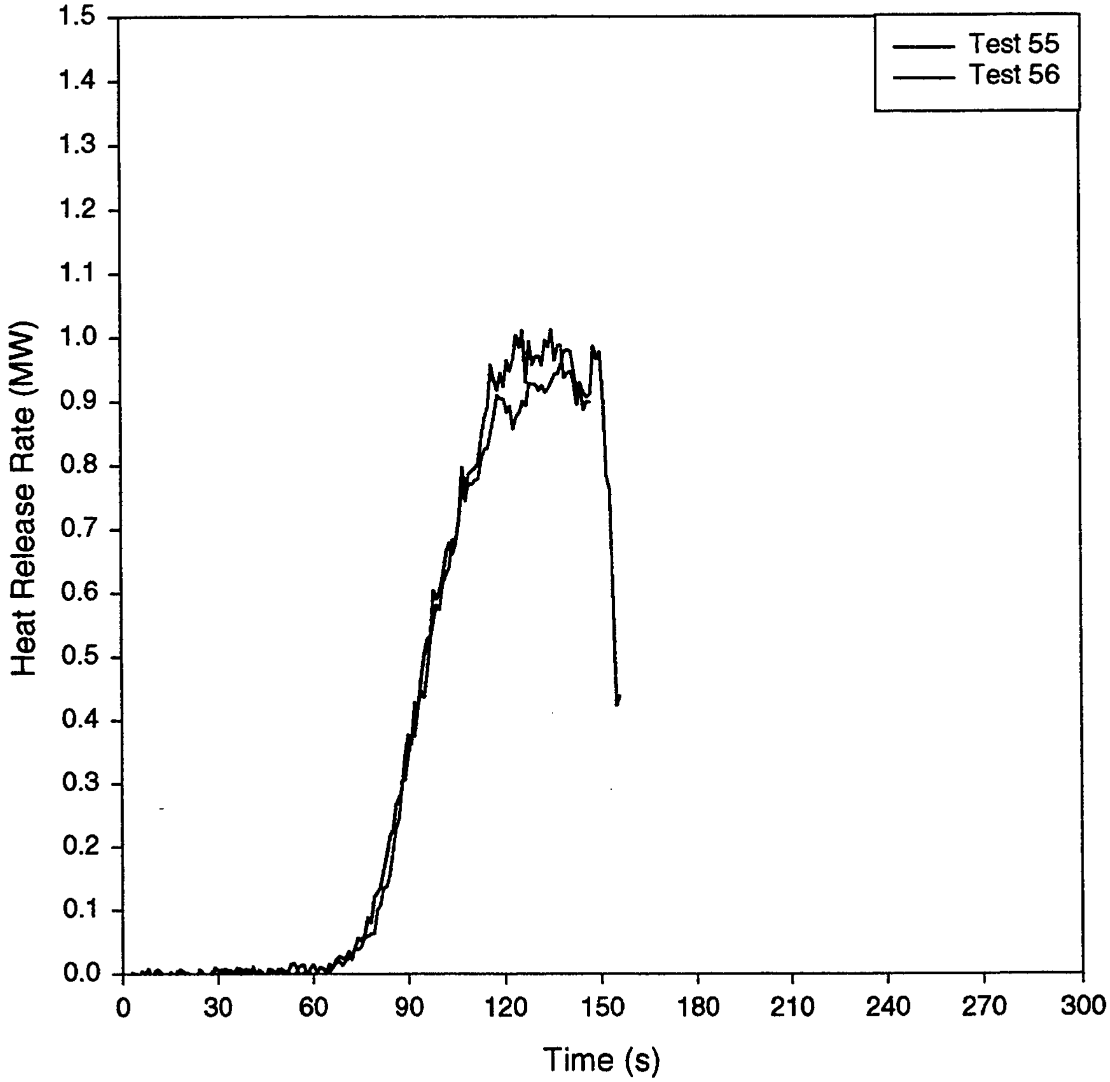
Comparison of heat release rates for 1.7 Lpm
unconfined spill fire with chopped IR at 20 m.



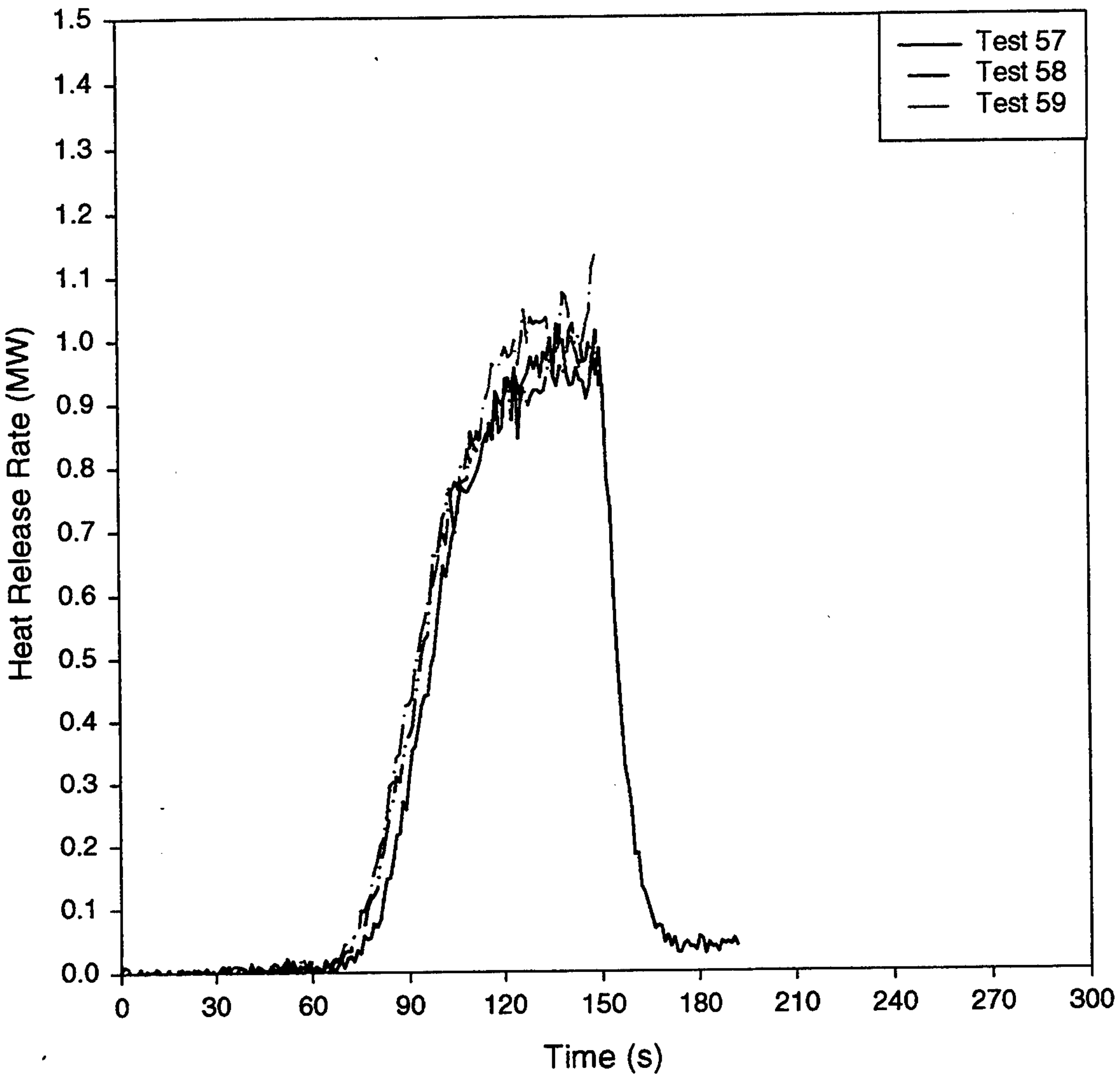
Comparison of heat release rates for 1.7 Lpm unconfined spill fires with chopped IR at 26 m.



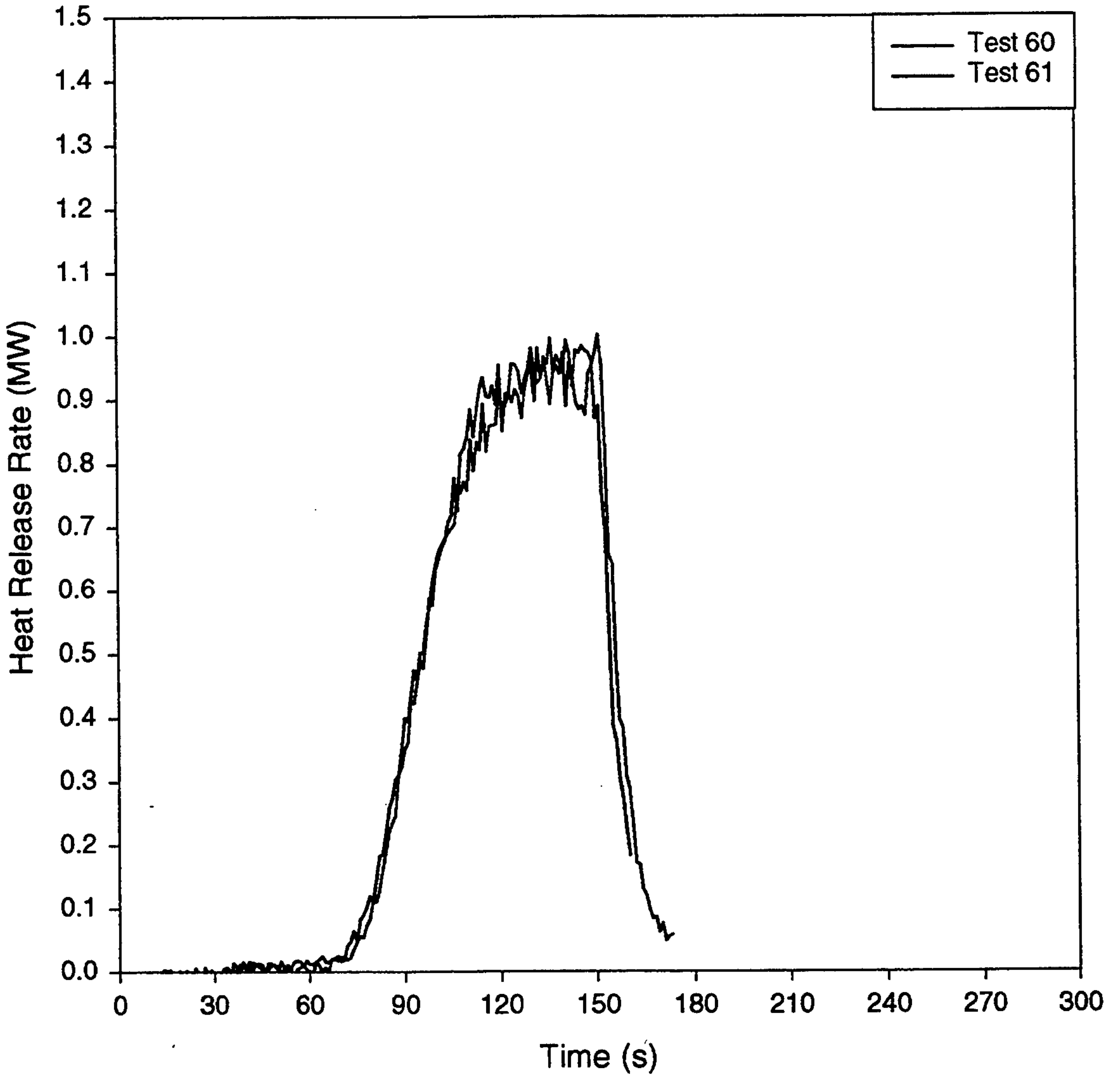
Comparison of heat release rates for 1.7 Lpm unconfined spill fires with obstructions 0-1.34 m ht.



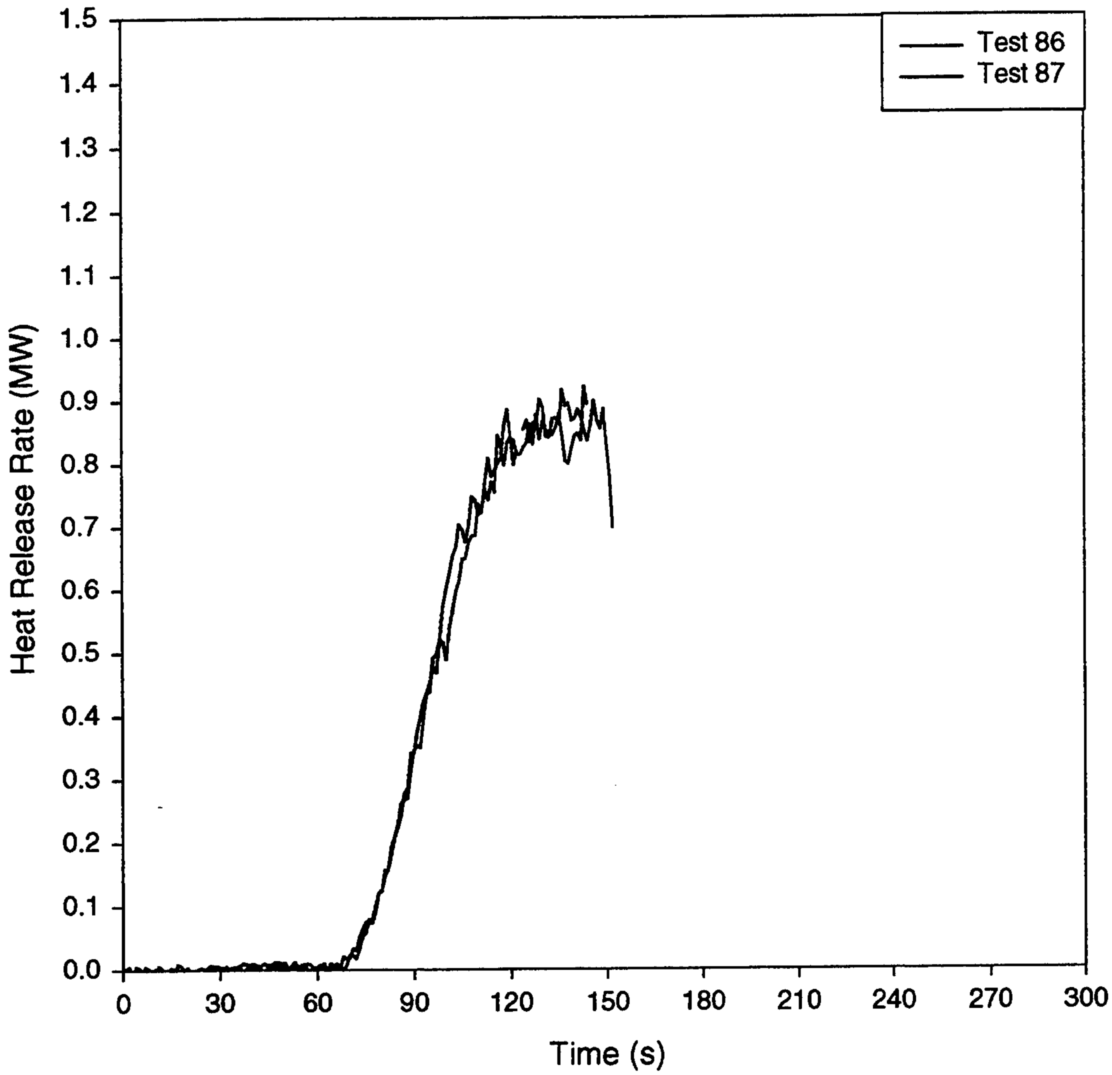
Comparison of heat release rates for 1.7 Lpm unconfined
spill fires with a moving obstruction 0-1.34 m in height.



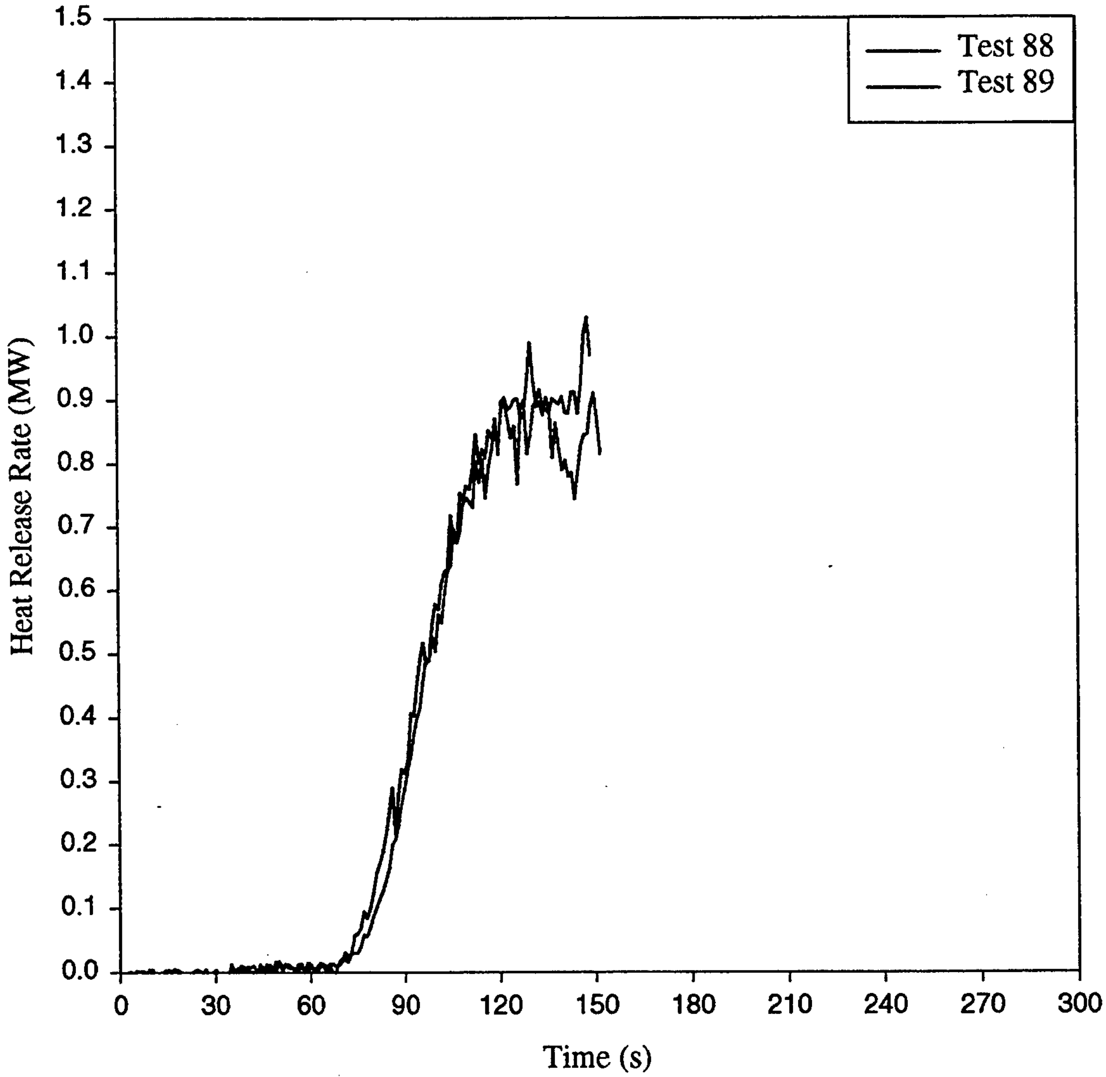
Comparison of heat release rates for 1.7 Lpm unconfined spill fires with an obstruction .3-2.3 m in height.



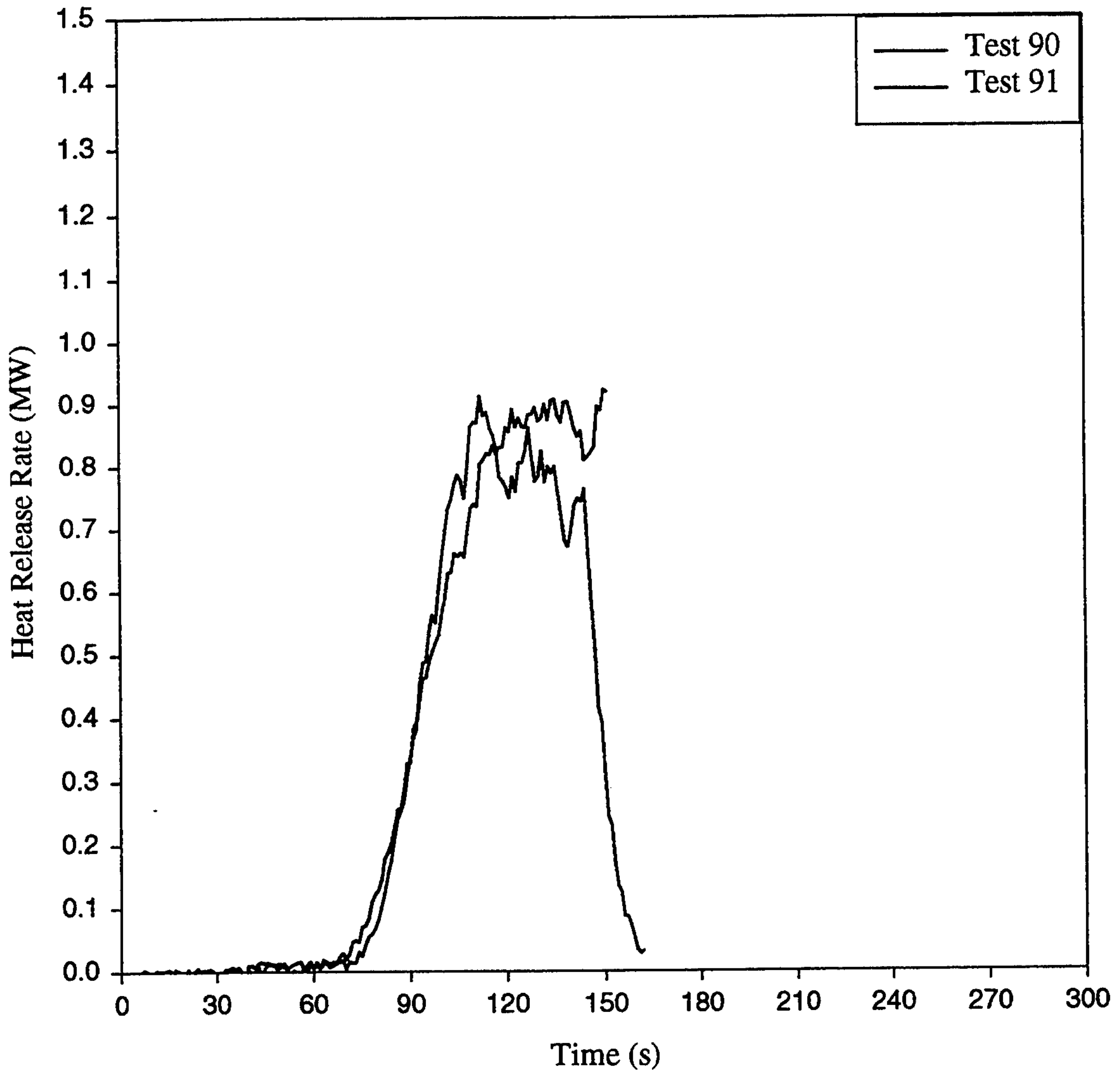
Comparison of heat release rates for 1.7 Lpm unconfined spill fires with a moving obstruction .3-2.3 m in height.



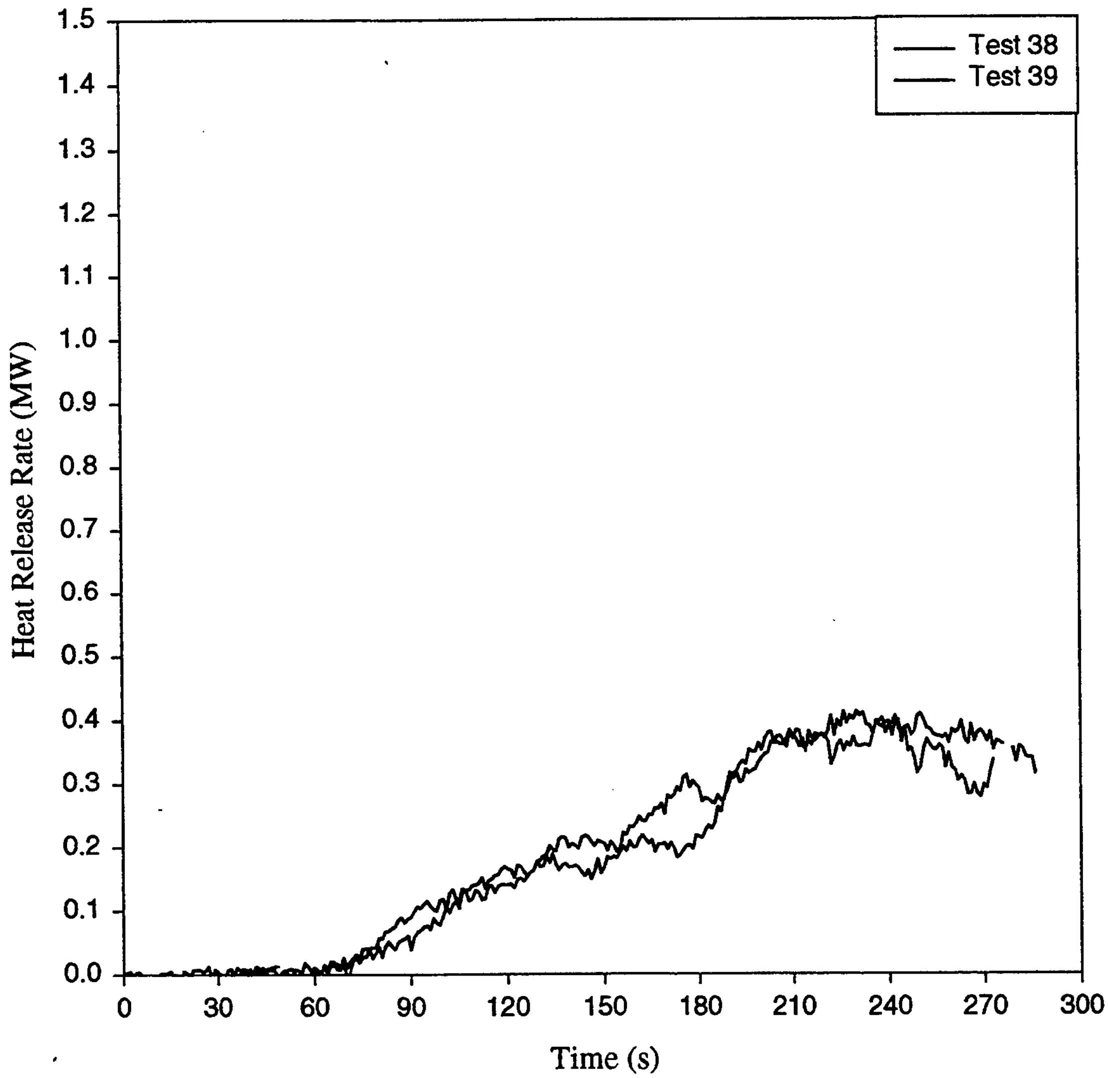
Comparison of heat release rates of 1.7 Lpm
unconfined spill fire with arc welding at 15 m.



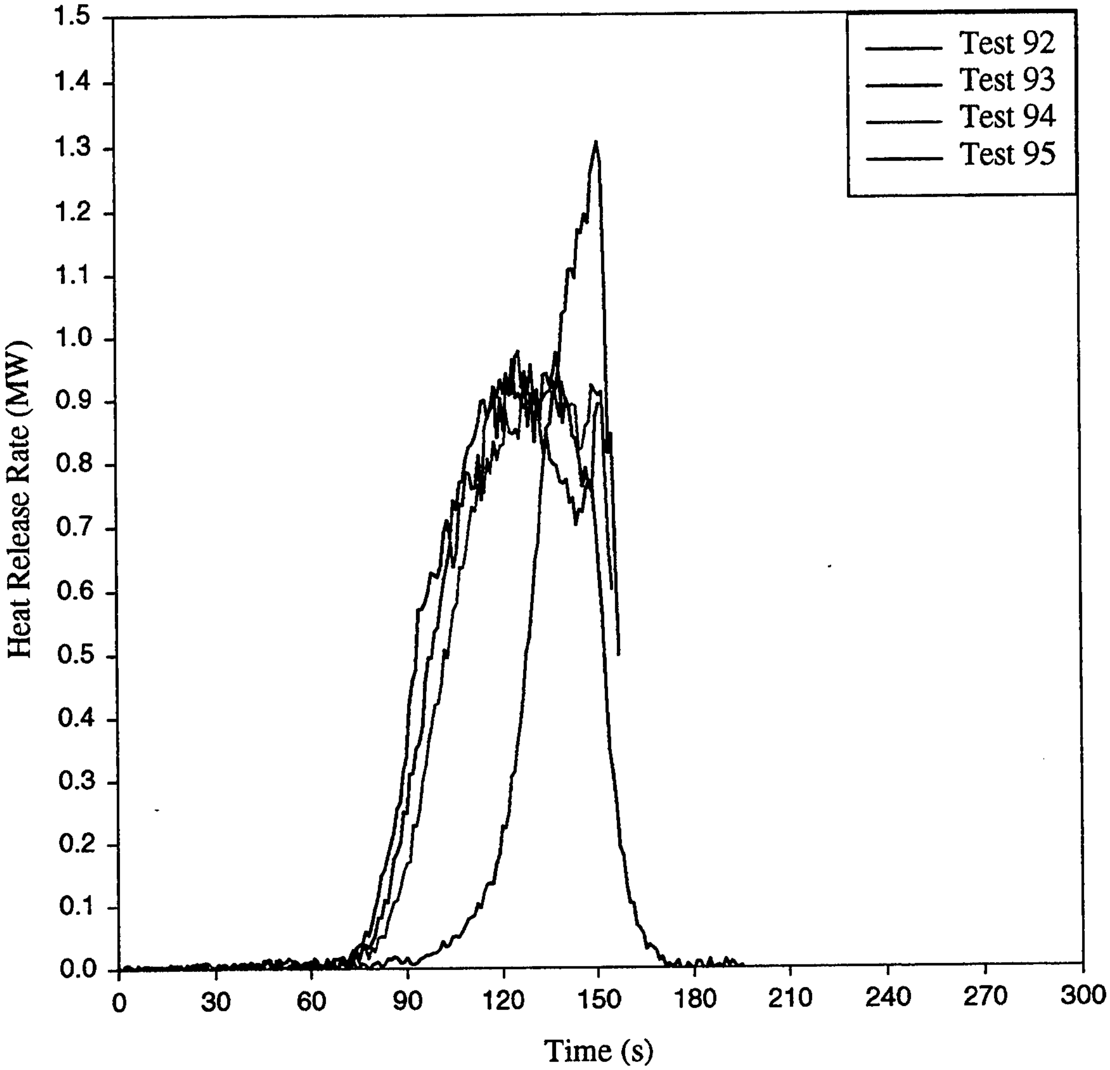
Comparison of heat release rates for 1.7 Lpm
unconfined spill fires with arc welding at 27 m.



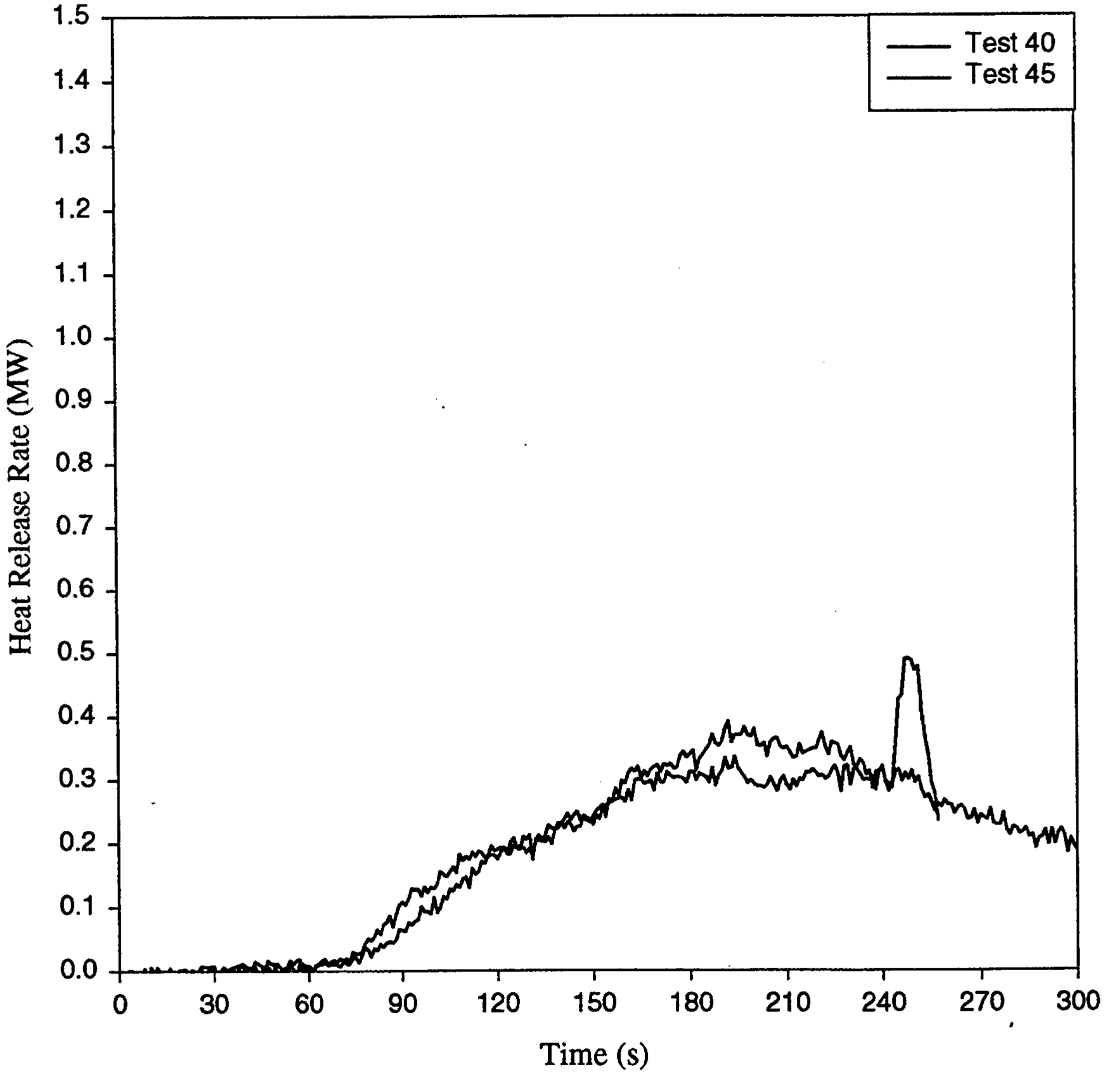
Comparison of heat release rates for 1.7 Lpm unconfined spill fires with doors open and lights on.



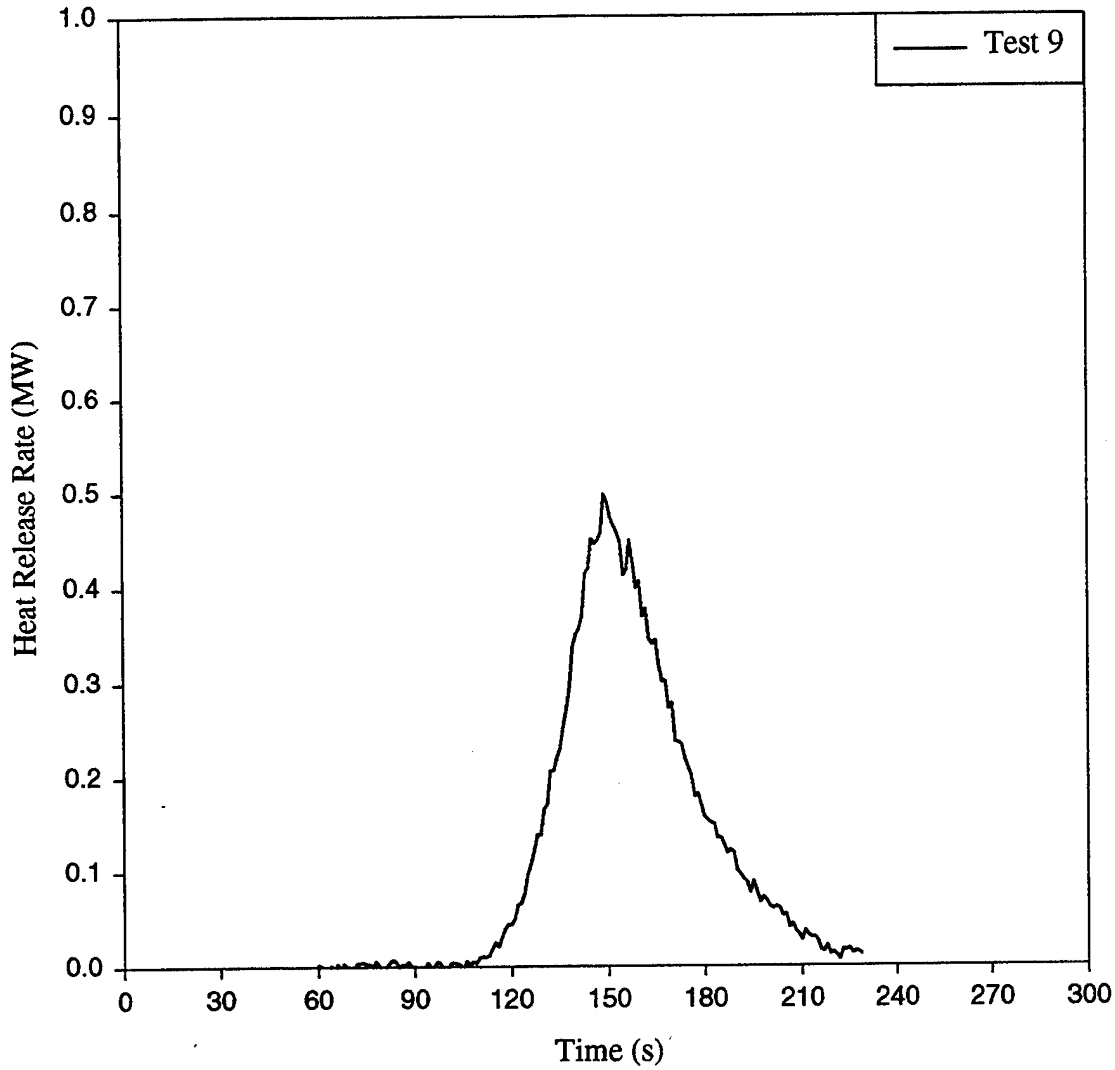
Comparison of heat release rates for 1.7 Lpm
confined in the y-direction spill fires.



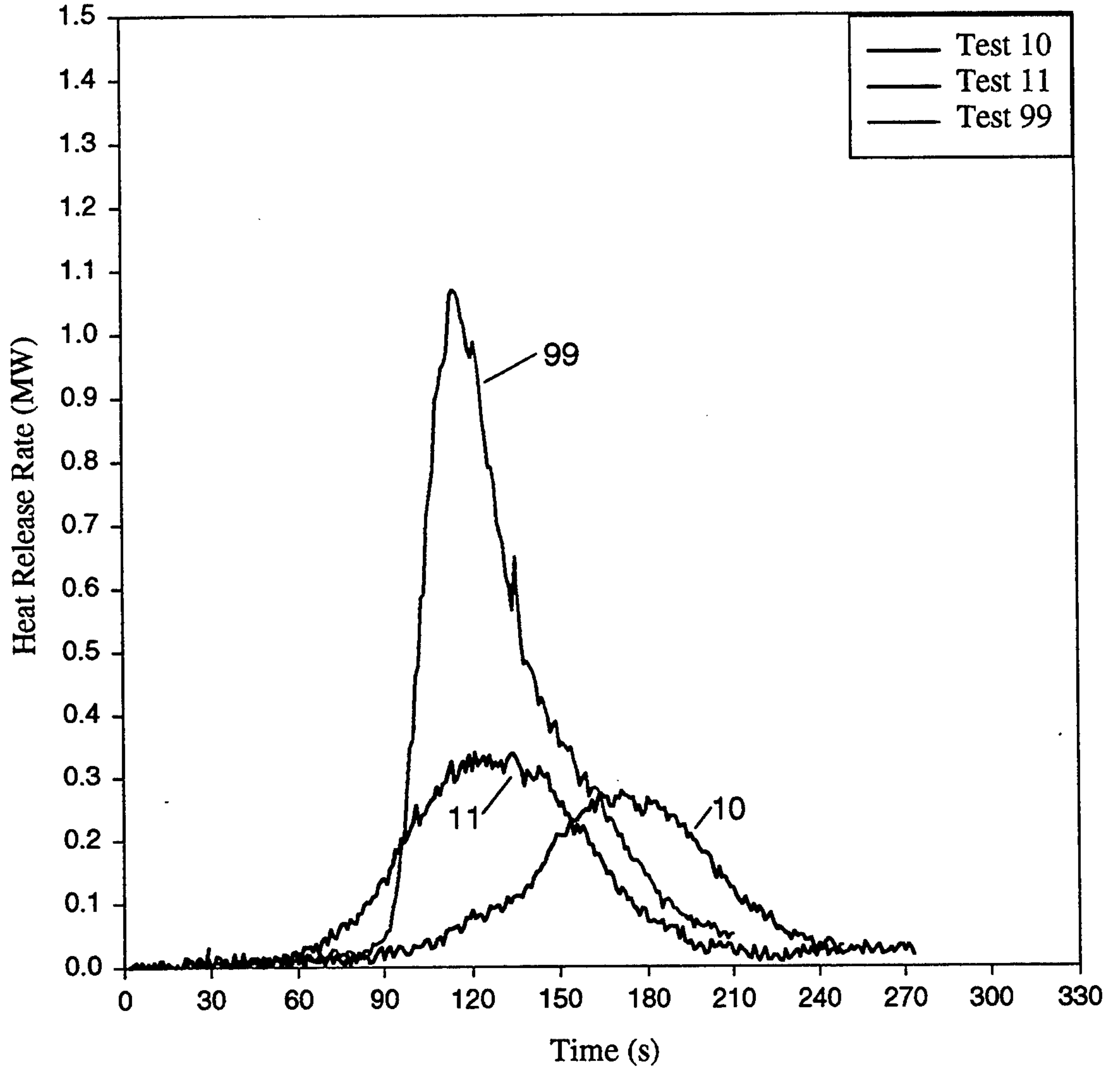
Comparison of heat release rates for 1.7 Lpm
unconfined spill fires using JP-5.



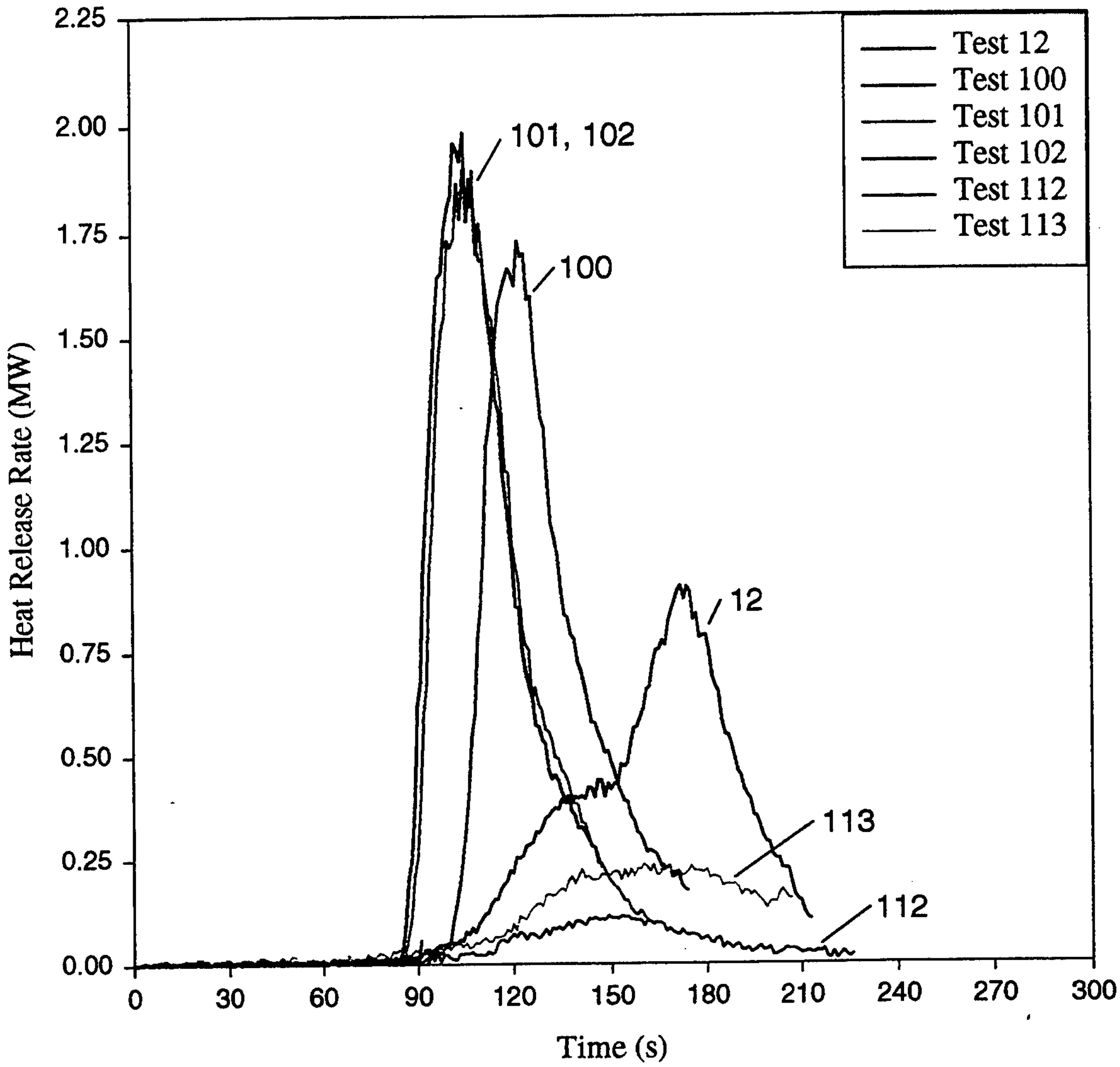
Comparison of heat release rates for 1.7 Lpm confined
in the y-direction spill fires using JP-5 fuel.



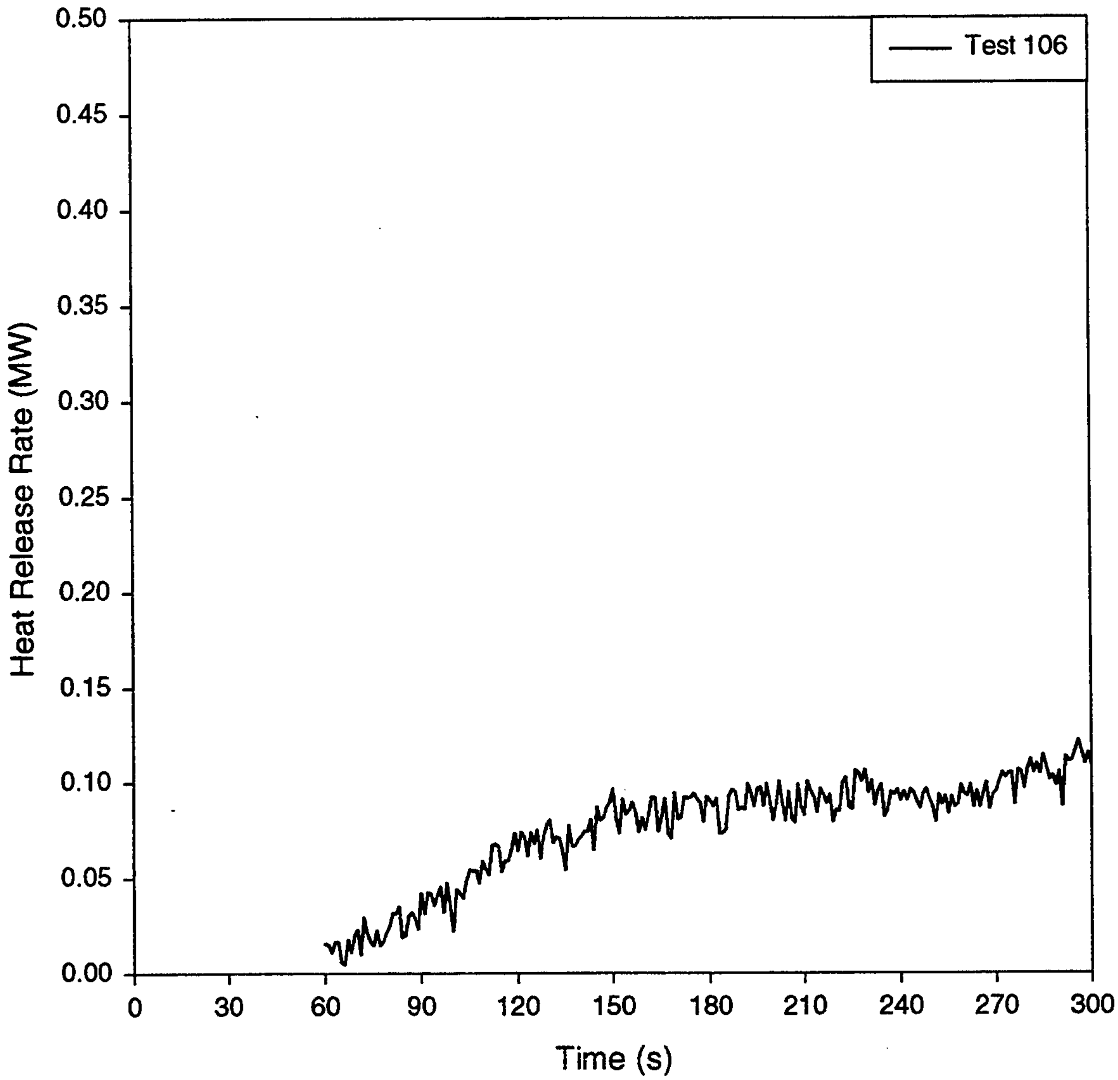
Heat release rate for 1 L fixed quantity spill.



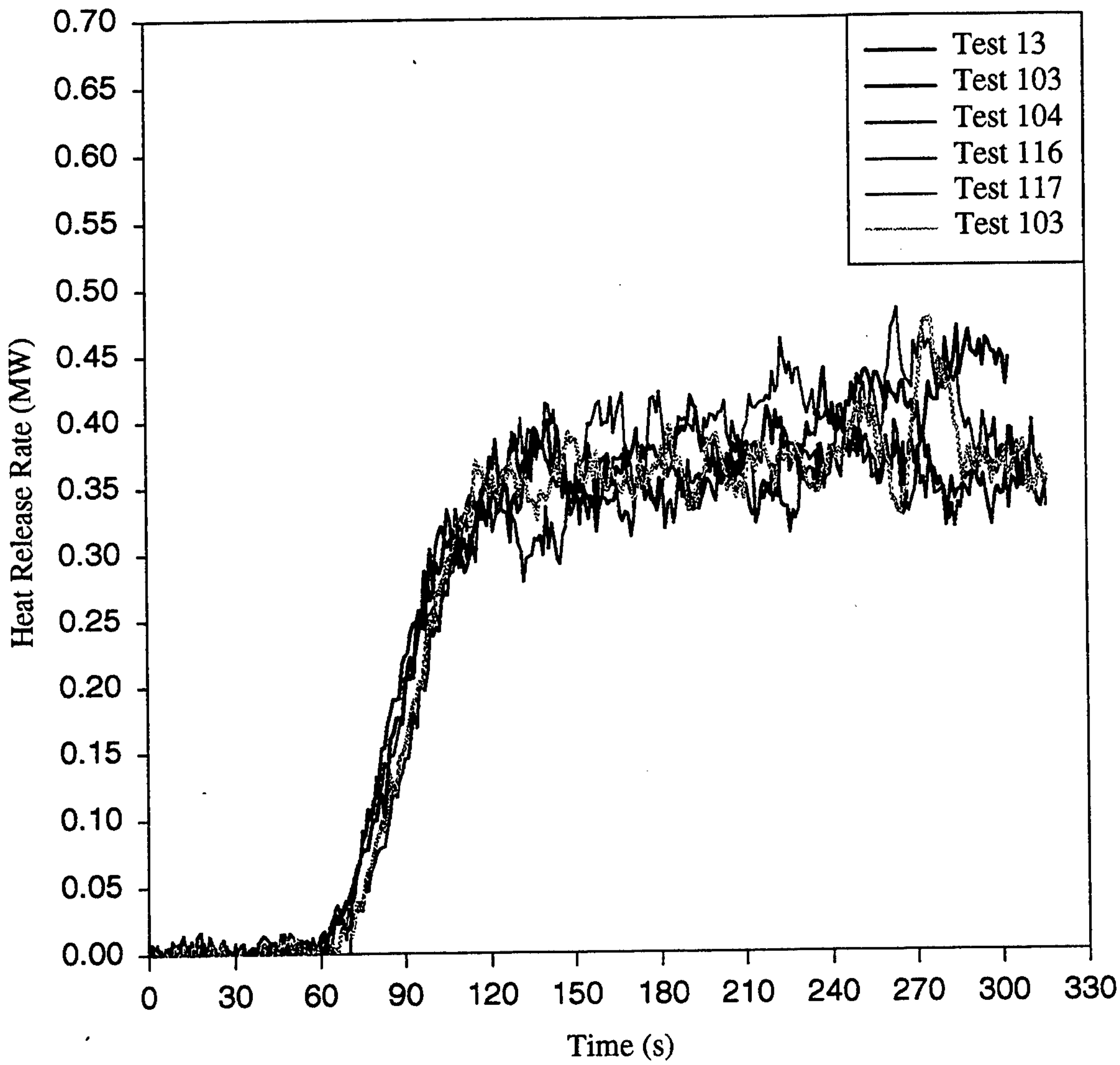
Comparison of heat release rates for 2 L fixed quantity JP-8 spill fires.



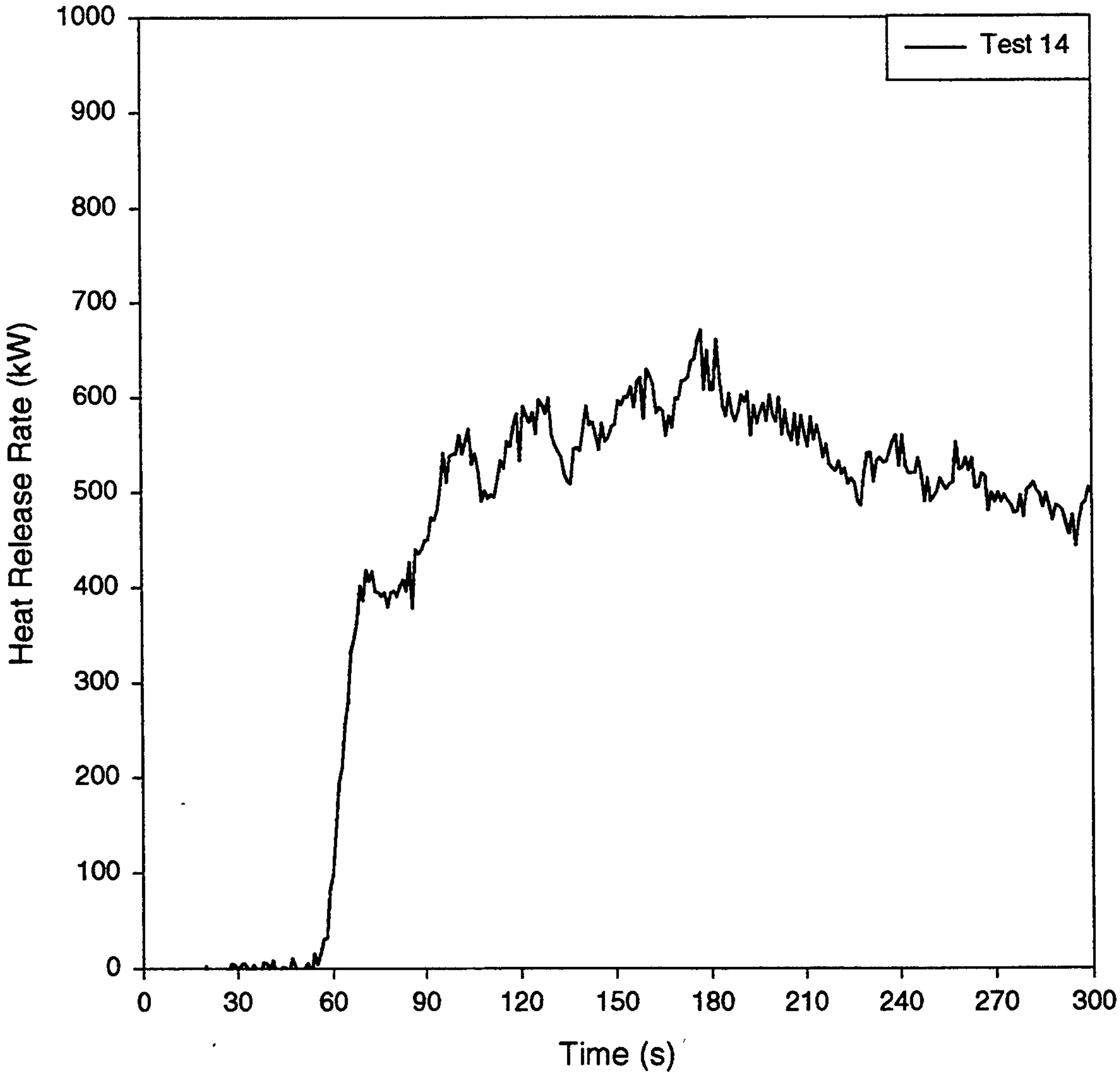
Comparison of heat release rates for 3 L fixed quantity JP-8 spill fires.



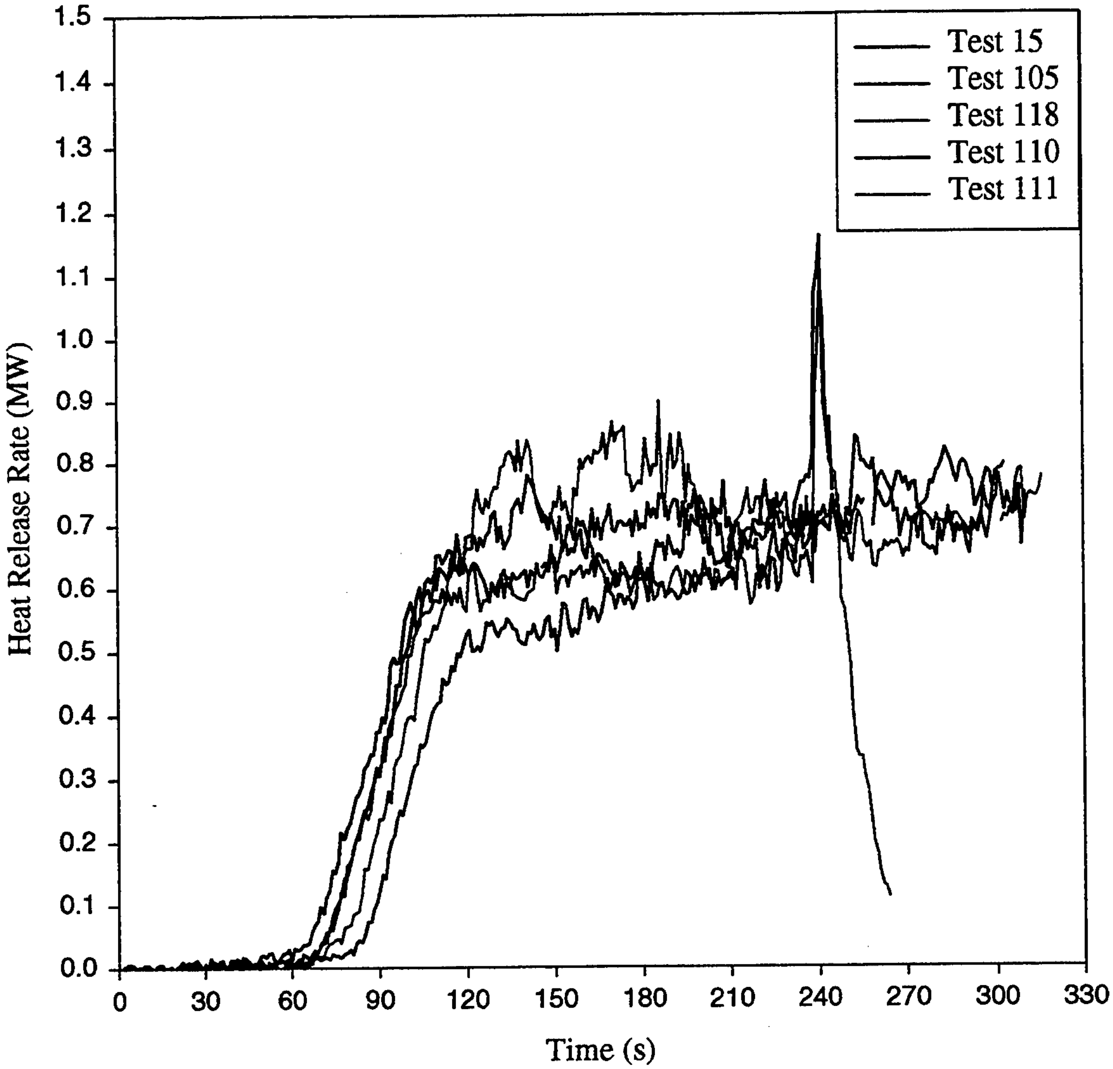
Heat release rate for .3 x .3 m pan fire.



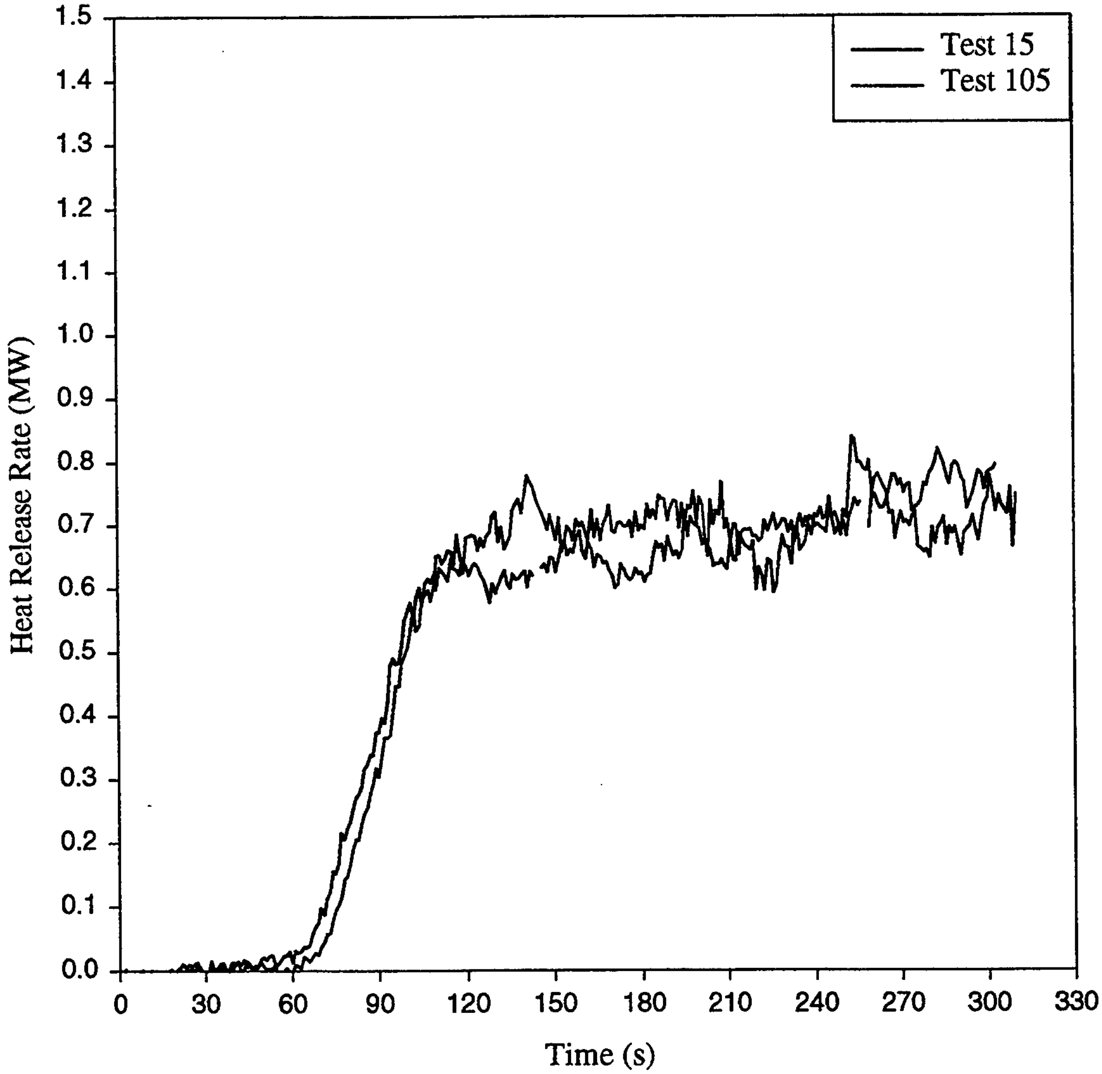
Comparison of heat release rates for .6 x .6 m JP-8 pan fires.



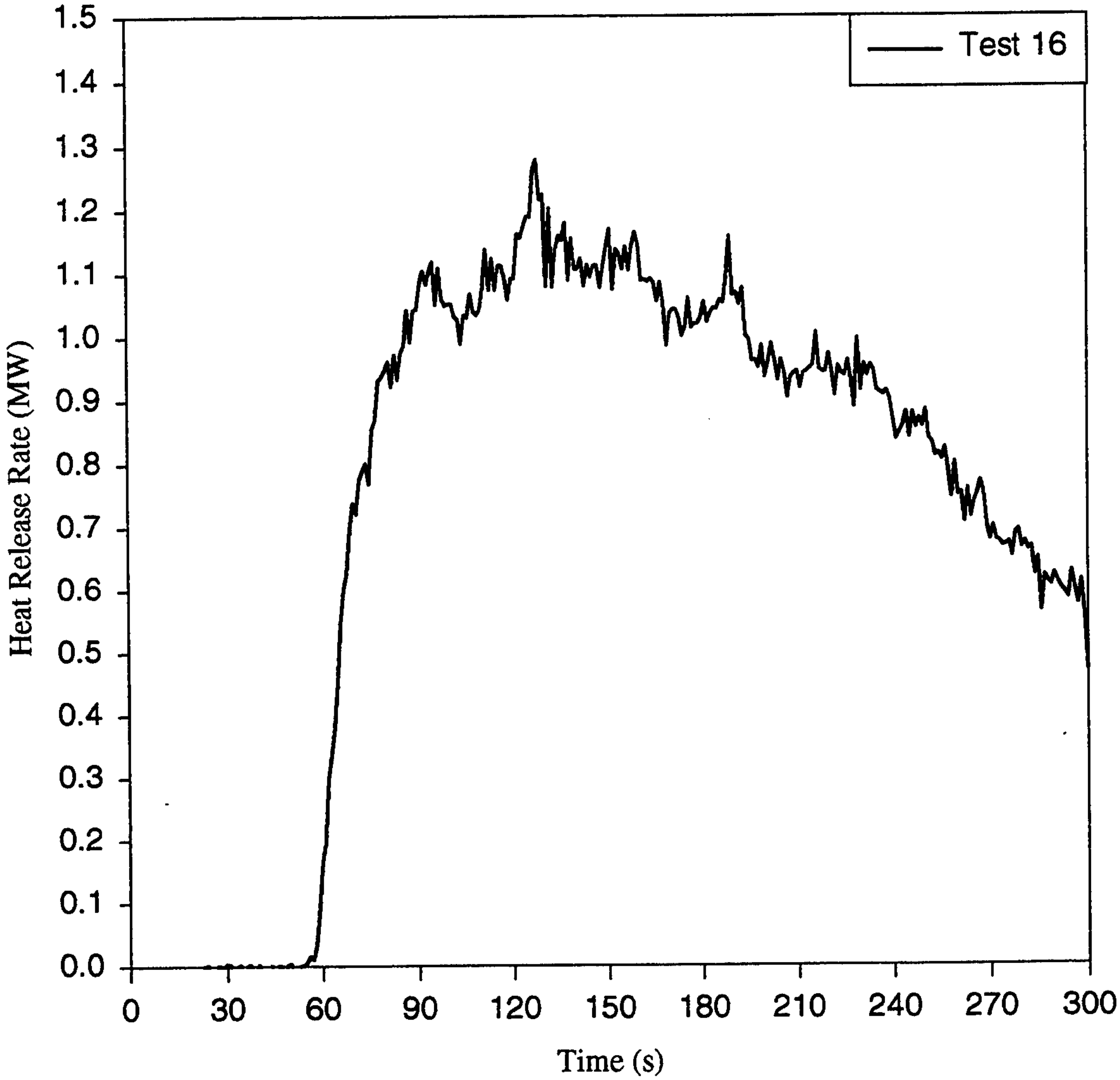
Heat release rate for 0.6 x 0.6 m gasoline pan fire.



Comparison of heat release rates for 0.91 m diameter JP-8 pan fires.



Comparison of heat release rates for 0.91 m diameter JP-8 pan fires.



Heat release rate .91 m diameter gasoline pan fire.

Appendix E

“Results of Optical Stress Immunity Tests”

Appendix E contains a report detailing the results of the optical stress immunity tests. The full reference for the report is

Y. P. Seguin and G. D. Lougheed, “Results of Optical Stress Immunity Tests” NRC Report No. B-4108.1, National Research Council Canada, December 18, 1998.

National Research Council Canada
Conseil national de recherches Canada

NRC·CNRC

Client Report

B-4108

Results of Optical Stress Immunity Tests

for

Hughes Associates, Inc.
3610 Commerce Drive
Suite 817
Baltimore, MD 21227-1652

18 December 1998

Institute for Research in Construction
IRC

RESULTS OF OPTICAL STRESS IMMUNITY TESTS

Author
Y. P. Séguin, CET

Author
G. D. Lougheed, Ph.D.

Approved
R. Thomas, Ph.D.,
Director, Fire Risk Management Program

Report No.	B-4108.1
Report date:	18 December 1998
Contract No.	B-4108
Reference:	Letter of Agreement dated 05 June 1998
Program:	Fire Risk Management

34 Pages
Copy No. 1 of 6 copies

RESULTS OF OPTICAL STRESS IMMUNITY TESTS

Y. P. Séguin and G.D. Lougheed

INTRODUCTION

The Naval Facilities Engineering Command (NAVFAC) is directing research to improve fire protection systems in military aircraft hangars. As part of this research, Hughes Associates Inc. (HAI) conducted a project to evaluate the performance of six optical fire detector (OFD) models. This included a full-scale test program using liquid hydrocarbon fuel spill and pan fires to determine detector response times. These tests are documented in a separate report prepared by HAI.

As part of the project, NAVFAC and HAI were also interested in determining the susceptibility of the detectors to other sources, which emit in the UV, visible and IR portions of the spectrum. For this purpose, the test procedure developed by the National Research Council of Canada (NRC) for the Department of National Defence (DND) was used. The development of the test procedure is documented in the report prepared for DND entitled "Qualification Testing for Optical Fire Detectors for Use in Multi-Function Hangars" [1]. The test procedure outlined in the DND report was used as the basis for the tests conducted in this project. This test procedure is attached (Appendix A).

A detailed description of the test procedure and arrangement is provided in Reference 1. These details are not duplicated in this report.

There were limited modifications to the test procedure and additional tests were also developed and conducted during the test program. These changes in the test procedure and additional tests used for this test program are described in the section entitled Test Procedure.

This report provides a summary of the test results for the optical stress tests, a brief discussion of the results and recommendations regarding modification of the test procedure.

DEFINITIONS

The following definitions apply to this report.

BIT	Built in test. Self test sequence conducted by detector at power-up and periodically during operation.
Blocked Element	Tests conducted with a detector element blocked using a layer of electrical tape. For OFD1, a metal disk was used in addition to the layer of black tape.
Chopping Wheel	A 1.2 m diameter wheel with 8 alternating open and closed sections was used to provide chopping at frequencies of 2, 5, 10 and 25 Hz. The detector was centred 460 mm from the centre of the wheel. Additional tests were conducted replacing the four open sections of

	the wheel with a partially open steel grid with 13 mm diameter holes on 19 mm centres.
Gridded Wheel	The 1.2 m diameter chopping wheel with the four open sections covered with a partially open steel grid with 13 mm diameter holes on 19 mm centres.
FOV	Detector field of view.
IR Source	1000 W Tungsten Halogen lamp operating at 120 VDC, except where otherwise indicated. This lamp also produces a small amount of UV emissions.
IR Shutter	Additional tests were conducted in which the OFD was covered with a black cloth after exposure to the optical stress.
Quartz IR Heater	Commercial quartz IR heater operated at its maximum output (rated at 1500 W by the manufacturer). This unit was also used for the optical stress tests conducted concurrent with the spill fire tests.
NA	Test not applicable.
No effect	A change in test procedure did not result in additional detector responses or change its sensitivity to the optical stresses.
Min./Max. Voltage	All detectors were tested at their nominal 24 V operating voltage. OFD6 was also tested at the minimum and maximum operating voltage.
OFD	Optical fire detector.
OFD Model	One of six optical fire detector models provided by three detector manufacturers. The detector models are designated as OFD1, OFD2, OFD3, OFD4, OFD5 and OFD6 consistent with the designations used for the spill fire tests.
OFD Specimen	One of six or seven detector units provided by the detector manufacturer for each detector model. These are designated as OFD#A to OFD#F. The letters A-F designate the detector location during the fire tests. If seven units were supplied, this additional unit is designated as OFD#G. This unit was not used in the fire tests.
Ramp	For the IR source, ramping involved shuttering the OFD for ≥ 1 min, extinguishing all light sources, removing the shutter, then nonlinearly increasing lamp voltage from 0 V to 120 V to give linear increase in illuminance to the maximum over a period of 5 min. For the UV source, the same test applied, except that the lamp was simply turned on and allowed to stabilize over a period of approximately 10 to 15 min.

Repowered Unshuttered	If the detector responded with sudden exposure to an optical stress condition, the unit was turned off and repowered exposed to the stress condition and the test continued. If the detector could not be repowered unshuttered without responding, the test was stopped and this result is noted in the Tables.
Response	The event in which the OFD under test signals the presence of fire.
Response Time	In the event of OFD response, response time is reported as the approximate time between exposure to the optical stress and detector response.
Stationary Test	Test involved placing OFD on a stationary platform, shuttering OFD for ≥ 1 min, then removing shutter and exposing OFD to the specified source for ≥ 30 s.
Swivel Test	Same as Stationary Test, except the OFD was placed on a platform which swivelled from –60° to +60° at the rate of 22.5°/s. The Swivel Test was always carried out immediately after the Stationary Test. For the third OFD specimen, additional tests were conducted with the detector swivelled at the rate of 11.25°/s.
Sudden Exposure	The detector was powered up and shuttered with a black cloth for ≥ 1 min. The cloth was removed exposing the detector to the optical source.
UV Blocking	Barr Associates Coated Si filter* (UV blocking filter) was used to block the UV emissions from the IR Source.
UV Source	1000 W Broken Metal Halide lamp operating at 115 VAC, except where otherwise indicated. (The outer glass envelope of the lamp was removed leaving only the inner quartz envelope which transmits emissions at 200-300 nm.)
90° Rotation	The detector was rotated 90° clockwise about the detector axis normal to the direction of sight.

TEST PROCEDURE

The tests were conducted in general accordance with the draft test procedure outlined in Appendix B of the report entitled "Qualification Testing for Optical Fire Detectors for Use in Multi-Function Hangars" [1]. This test procedure is attached as Appendix A. The changes to the test procedure were as follows:

* Certain commercial products are identified in this report in order to adequately specify the experimental procedure. In no case does such identification imply recommendations or endorsement by the National Research Council, nor does it imply that the product or material identified is the best available for the purpose.

1. The on-off test sequence was not included. Previous tests indicated that this test did not produce any detector responses.
2. Except for detector Model OFD6, the detectors were operated at a nominal 24 V operating voltage. OFD6 was also tested at the extremes of its operating range (18 and 32 V) as well as 24 V.

All the standard tests were conducted once on three specimens of each detector model at an operating voltage of 24 V. With the first two specimens of each detector model, tests were conducted at chopping frequencies of 0, 5, 10 and 25 Hz. The third specimen was tested at chopping frequencies of 0, 2, 5 and 10 Hz. Tests were also carried out on the UV/IR detectors with an UV blocking filter (test series with IR source only).

Additional tests were conducted on the third specimen for each detector model. These tests were:

- 90° rotation of the detector about the horizontal axis, rotated clockwise looking towards the detector (test series with IR source only for all detector models);
- individual detection elements blocked (test series with IR source only for all detector models except OFD2);
- OFD6 was tested with minimum and maximum power supply voltages (test series with IR source only);
- the specimen was swivelled at 11.25°/s in addition to the standard 22.5°/s swivel velocity for tests with the IR source;
- the specimen was tested with a rapid change from full exposure to shuttered condition (IR shutter) for the tests with the IR source at chopping frequencies 0, 2, 5 and 10 Hz;
- the third OFD specimen tested was not cleaned after exposure to fuel spill fire tests;
- OFD1, OFD3, OFD4 and OFD6 models were tested with a partial half-gridded wheel (test series with IR source only) with chopping frequencies of 2, 5, 10 and 25 Hz.
- detectors were tested with a quartz IR heater placed at distances of 2 and 4 m. The standard series of tests with the IR light source (sudden exposure and swivel at all chopping frequencies) was conducted at both distances. These tests were not performed in combination with other sources of radiation.

Any additional tests carried out on each of the detector models are noted in the Section entitled Results of Additional Tests.

EQUIPMENT USED

The following equipment was used to perform the optical stress immunity tests:

- Wavetek arbitrary waveform generator Model 395;
- Kepco power supply Model #JQE 36-15M;
- Xantrex XKW 150-20 DC power supply;
- Elgar AC line conditioner Model 6006B;
- Minolta illuminance meter Model T-1M;
- Graseby Optronics S370 optometer;
- Fluke 8842A multimeter;
- Sylvania 1000 W tungsten halogen lamp;
- Sylvania 1000 W metal halide lamp with glass envelope removed;
- Hubbell metal halide lamp ballast and fixture housing;
- Linear translation stage mounted on tripod for halogen lamp distance adjustments;
- Imatronic laser Model LDL175/670/3 mounted on tripod for lamp alignment;
- 1220 mm diameter custom chopper wheel;
- Baldor 1/3 hp motor and Baldor speed drive Model BC140 for chopper wheel control;
- Hercules shaft encoder for motor revolution measurements;
- Omega process meter Model DP25-E (for chopping frequency display) connected to the Hercules shaft encoder via an NRC-built custom interface circuit;
- Custom rotating and elevating table controlled by an NRC-built stepper motor based control circuit;
- Barr Associates Coated Si filter (UV blocking filter);

TEST RESULTS

The results for each detector model are summarized in Tables 1-6. Results are presented as ratios of the number of OFD responses per number of tests.

For Detector Model OFD1, Specimens OFD1E and OFD1F were tested on June 29, 1998 and July 1, 1998 prior to the spill fire tests. Specimen OFD1D was tested on July 23-24, 1998. Additional tests using the half gridded wheel, element blocking and the IR quartz heater were conducted with Specimen OFD1D on July 29-30, 1998. The tests with the detector elements blocked were repeated on September 4, 1998. The results for this detector model are summarized in Table 1.

For Detector Model OFD2, Specimens OFD2F and OFD2G were tested on June 30, 1998 and July 2, 1998 prior to the spill fire tests. Specimen OFD2D was tested on July 27, 1998. Tests with the IR quartz heater were conducted with this specimen on September 3, 1998. The results for this detector model are summarized in Table 2.

(Because of the design of this detector, it was impossible to effectively block the detector elements. Thus, tests with the detector elements blocked were not conducted for this detector model.)

For Detector Model OFD3, Specimens OFD3F and OFD3G were tested on June 30 and July 1, 1998 prior to the spill fire tests. Specimen OFD3D was tested on July 27, 1998. Additional tests using the half-gridded wheel, blocked elements and the IR quartz heater were conducted with specimen OFD3D on July 29, 1998. The tests with the blocked elements were repeated on September 9, 1998. The results for this detector model are summarized in Table 3.

For Detector Model OFD4, Specimens OFD4C was tested on July 3, 1998 prior to the spill fire tests. Specimens OFD4D and OFD4E were tested on July 20-22, 1998. Additional tests using the half-gridded wheel, blocked elements and the IR quartz heater were conducted with specimen OFD4D on July 29, 1998. The tests with the blocked elements were repeated on September 4, 1998. The results for this detector model are summarized in Table 4.

For Detector Model OFD5, Specimens OFD5C and OFD5B were tested on July 2-3, 1998 prior to the spill fire tests. Specimen OFD5D was tested on July 24, 1998. Additional tests with specimen OFD5D using the IR quartz heater and blocked elements were conducted on September 3-4, 1998. The results for this detector model are summarized in Table 5.

For Detector Model OFD6, Specimens OFD6B and OFD6C were tested on July 4-5, 1998 prior to the spill fire tests. Specimen OFD6D was tested on July 28, 1998. Additional tests using the half gridded wheel, blocked elements and the IR quartz heater were conducted with Specimen OFD6D on July 29, 1998. The tests with the blocked elements were repeated on September 4, 1998. The results for this detector model are summarized in Table 6.

RESULTS OF ADDITIONAL TESTS

Additional tests were conducted with some or all detector models. The results of these tests are provided in Tables 1-6 and are summarized as follows:

1. UV Blocking. There were no responses for the 3 UV/IR detector models that were tested with the UV blocking filter and the IR Source. These detector models did respond to the unfiltered IR Source (Tables 1, 2 and 5).

2. 90° rotation. There was no change in the detector responses when the detectors were rotated 90° clockwise about the detector axis.

3. Butane lighter. All six detector models tested did respond to the flame from a butane lighter (53 mm high flame, 300 mm from the detector on axis). The results are provided in Table 7.

4. Penlight. OFD3 responded to illumination from a krypton bulb penlight waved in front of the detection elements. However, it was difficult to get a response and required a

random exposure of the detection elements. The other five detector models did not respond to this source.

5. IR shutter. Shuttering the OFDs from full exposure to the IR Source did not produce any additional responses

6. Minimum/Maximum operating voltage. Additional tests for OFD6 at its minimum and maximum operating voltage (18 and 32 V) using the IR Source test sequence (0, 2, 5, and 10 Hz chopping frequencies and 11.25°/s and 22.5°/s swivel velocity) did not produce any responses.

7. Quartz IR heater. Tests with the Quartz IR heater with Detector Models OFD1, OFD2, OFD3, OFD5 and OFD6 did not produce any responses. Detector Model OFD4 did respond when viewing the source chopped at 0.3-0.5 Hz. The six detector models responded to a butane lighter flame (53 mm high flame, 300 mm from the detector on axis) equally with or without the heater source. The response times for the three test conditions (flame without IR heater, flame with IR heater at 2 m and flame with IR heater at 4 m) are summarized in Table 7.

8. Blocked Elements. Detector Models OFD1, OFD3, OFD4, OFD5 and OFD6 were tested with individual detector elements blocked. OFD1 and OFD4 have two detection elements. The detection elements on the left and right side of the detector as viewed from the front are denoted as Element 1 and 2, respectively. OFD5 has two detection elements with the element on the top and bottom designated as Element 1 and 2, respectively. Detector Models OFD3 and OFD6 had three detection elements. The top, middle and bottom elements are designated as Elements 1, 2 and 3, respectively. The results of the tests for detector responses with blocked elements are provided in Table 1, 3, 4, 5 and 6. During the tests, it was noted that, for some detectors, the built in tests (BIT) used by the detector provided a fault condition if an element was blocked. Observations regarding the detector self tests as well as general remarks on the effect of the blocked element on detector response to the optical stresses are provided in the following comments for each detector. It should be noted, however, that there was not a systematic investigation of the detectors' BIT. The observations regarding self-tests are provided as additional information.

   OFD1

   - Did not respond when Element 2 was blocked.
   - Detector model was very sensitive when Element 1 was blocked. The specimen responded to the same sources as used in the standard tests with the IR Source and shown in Table 1 when the element was covered with two layers of black tape. However, when the element was blocked with a metal plate and several layers of black tape, the specimen did not respond.
   - Blocking Element 1 at power-up produced a fault condition as indicated by the LED and the closing of the fault relay. If this element was blocked after the detector powered, a fault condition is indicated after the subsequent BIT test.
   - Blocking Element 2 did not produce a fault condition, even after the BIT test.

OFD3

- Blocking Elements 1 and 3 did not produce a fault condition with the BIT test.
- Power LED indicated BIT failure when Element 2 was blocked. (Blocking only the detector element does not always produce a BIT failure at power-up. Covering the test lights, which are located next to the detector element, as well as the detector element repeatedly produced a BIT failure. When BIT failure occurred at power-up, a second BIT was attempted after 1 min. The OFD passed on the second attempt even though the detector element was still covered.)
- There were intermittent responses under ambient light conditions with Element 2 covered by tape and the other two elements uncovered.

OFD4

- No responses to the test conditions and no trouble indicated by the detector relay during a 30 min test period.

OFD5

- Did not respond with either detector element blocked.
- No fault conditions indicated with blockage of the detector elements.

OFD6

- No fault conditions indicated with blockage of the detector elements.
- No responses were produced when Element 1 was blocked.
- Responded when Element 2 was blocked with exposure to the IR Source from shuttered condition at 2 and 5 Hz.
- Responded when Element 3 was blocked with exposure to the IR Source from shuttered condition at 2 Hz (this response was difficult to reproduce).

9. Gridded wheel. Tests with the half-gridded chopping wheel did not produce any significant changes in responses for the four detector models tested (OFD1, OFD3, OFD4 and OFD6). OFD1 responded with sudden exposure to the IR Source in the swivel tests and at the same chopping frequencies as with the standard chopping wheel. The results indicate this detector model was slightly less sensitive when tested with the half-gridded wheel. Detector Model OFD4 responded in the 0.3 to 0.8 Hz range similar to the tests with the standard chopper wheel. However, the detector was very sensitive to 2 Hz chopping with the half-gridded wheel. There were no responses at the other chopping frequencies. OFD3 and OFD6 did not respond to this test condition.

10. 11.25°/s swivel. The tests with a 11.25°/s swivel speed did not produce any significant differences except for the following:

    - OFD1 responded with the IR source chopped at 10 Hz.
    - OFD4 responded with 22.5°/s swivel velocity and no chopping of the source but did not respond under the same conditions with 11.25°/s swivel velocity.

DISCUSSION AND REMARKS

1. This report provides the results of the tests to determine the response of six optical fire detector models to a variety of optical stresses as outlined in the test procedure (Appendix A). The objective of the test specification is to provide a practical test program, which determines a detector's ability to reject false optical stimuli while recognizing that 100% assurance is impossible. The procedure uses a limited number of optical stress sources to simulate a range of potential sources of UV and IR in an aircraft hangar. It is not intended to simulate all sources. However, based on the results provided in this report and in Reference 1, it can be concluded that the test procedure can be used as a basis for assessing the susceptibility of optical fire detectors to potential false alarm sources represented by the test conditions. The results can also be used for pass/fail criteria.

2. All possible sources of UV, visible and IR emissions that can be present in aircraft hangars are not covered by the test procedures. The potential for response to non-fire situations and the resulting consequences should always be considered in the design of a fire protection system using optical fire detectors.

3. Four of the six models tested in this test series were also tested in the previous work conducted by NRC on behalf of DND. These are Detector Models OFD1 (Sample 3A), OFD3 (Sample 5), OFD4 (Sample 7) and OFD5 (Sample 8). The results for these tests are provided in the report entitled "Qualification Testing for Optical Fire Detectors for Use in Multi-Function Hangars" [1]. The number in the brackets indicates the comparable detector model in the previous test series. The results of the present tests are consistent with those from the previous test program except for OFD4. One specimen in this test series consistently responded during swivel tests. There were two cases of this occurring during the previous tests. However, the response could not be replicated. Also, in additional testing with this model, it was determined that it was sensitive with chopping in the range of 0.3-0.8 Hz.

4. For Detector Models OFD1 and OFD4, one of the three test specimens responded more readily to the test conditions.

5. In terms of performance for the optical stresses used in this test series, two detector models (OFD3 and OFD6) responded to a very limited number of test conditions. Two detector models (OFD1 and OFD4) did respond to a range of test conditions. The other two detector models responded to a wider range of test conditions.

TEST PROCEDURE RECOMMENDATIONS

Based on the results of this test series coupled with the results of the previous test series conducted for DND, the following recommendations are made regarding the test method to evaluate the effect of optical stresses on OFDs:

1. None of the OFDs tested showed any effect of changing the supply voltage. That is, they did not demonstrate any increase in sensitivity to optical stresses at the upper or lower extreme of the stated operating voltage range compared with the 24 V nominal

operating voltage. It is recommended that the nominal voltage should be used when testing OFDs.

2. None of the OFDs used in the DND test series responded to the on/off test included in the procedure for this series of tests. Most modern detectors include a self-check test which is conducted when the detectors are powered. This negates the effect of the on/off test. This test should be removed from the procedure.

3. For those detectors, which were sensitive to chopped sources, the highest sensitivity was at the lower frequencies (0-10 Hz). Tests at 2 Hz should be included in the test procedure.

4. The 1000 W Tungsten Halogen lamp used as the IR source does produce a small amount of UV. Tests with UV blocking should be conducted for UV/IR detectors, which respond to this source. These tests determine if the detector response is due to IR emissions or to the combination of low UV emissions combined with the IR emissions.

5. Tests with the Quartz IR heater can be used to determine detector sensitivity to IR emissions. There were no major differences noted between tests conducted with the heater 2 m or 4 m from the detector. Tests with the detector at 2 m are recommended. The results of these tests combined with those obtained with the 1000 W Tungsten Halogen lamp with and without UV blocking provide a basic evaluation of detector susceptibility to IR and IR combined with low levels of UV.

6. Tests with the detector rotated 90° had no effect for the detectors used in this test series. There were detectors in the previous test series for which this test condition did produce a change. However, this effect was generally symptomatic of the detector being sensitive to asynchronous chopping for the detector elements. This stress is also evaluated using the gridded wheel. Since the latter tests provide a better overall evaluation of the potential effect of randomly chopped sources, it is recommended that the gridded wheel tests should be included in the test procedure rather than the tests with the detector rotated 90 degrees.

7. There are detectors that will respond to the tests with the penlight. However, these tests are not easily replicated and provide little or no information on the overall susceptibility of the detectors. This test should be removed from the test procedure.

8. The detectors were more sensitive to sudden exposure to the source than to shutter tests in which the source was rapidly blocked. The former tests are inherent in the standard test procedure. Although the IR shutter test could be easily added to the standard test procedure, it is not recommended.

9. There were no significant differences between the tests with the two swivel speeds. The 22.5°/s swivel speed is at the high end of the range of velocities that would occur in a hangar. However, since more detectors were evaluated at the higher swivel speed providing a larger database, this swivel speed is recommended for the test procedure.

10. Because of the differences in detector configurations, it was difficult to develop a systematic procedure for evaluating the effect of blocked detector elements. It was also difficult to replicate the situations in which there was an effect on the detector. Therefore, tests with blocked elements are not recommended for the test procedure.

REFERENCES

1. Ouellette, M.J., Lougheed, G.D., Séguin, Y.P. and Leber, A.M., Pre-Qualification Testing for Optical Fire Detectors for use in Multi-Function Hangars, Report A-4218.1, National Research Council of Canada, Ottawa, 1998.

Optical Stress				Results Standard Tests				Results Additional Tests										Note: All swivels were perfor[m...]				
				Stationary Test		Swivel Test (22.5°/s)		Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			Quartz IR Heater				Min./I Volt.
																		at 2 m		at 4 m		
										(Stationary)	(22.5°/s Swivel)	(11.25°/s Swivel)	(Stationary)	(Swivel)	(Stationary)	(22.5°/s Swivel)	(11.25°/s Swivel)	(Stationary)	(Swivel)	(Stationary)	(Swivel)	
Stress Condition	IR Source	UV Source	Chopping Frequency (Hz)	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Respo[nses,] No. T[ests]
a	Ramp	Off	0	1/3	120	NA		NA	NA	0/1	NA	NA	0/3	NA								
b	On	Off	0	3/3	1-4	1/3		0/1	0/1	1/1	0/1	1/1	0/3	0/3								
c	On	Off	0.3-0.8																			
d	On	Off	2	1/1	1-2	****		****	****	1/1	****	****	0/1	0/1	1/1	1/1	1/1					
e	On	Off	5	3/3	1-4	3/3 Note 1		1/1	0/1	1/1	1/1	1/1	0/3	0/3	1/1	0/1	1/1					
f	On	Off	10	3/3	1-4	1/3 Note 2		1/1	0/1	1/1	0/1	0/1	0/3	0/3	1/1	1/1	0/1					
g	On	Off	25	2/2	1-4	0/2							0/2	0/2	1/1	0/1	0/1					
h	Off	Ramp	0	0/3		NA																
i	Off	On	0	0/3		0/3																
j	Off	On	2	0/1		0/1																
k	Off	On	5	0/3		0/3																
l	Off	On	10	0/3		0/3																
m	Off	On	25	0/2		0/2																
n	Ramp	On	0	0/3		NA																
o	Ramp	On	2	0/1		NA																
p	Ramp	On	5	2/3	180	NA																
q	Ramp	On	10	0/3		NA																
r	Ramp	On	25	0/2		NA																
s	On	On	0	3/3	1-4	0/3																
t	On	On	2	1/1	1-2	****																
u	On	On	5	3/3 Note 1	1-4	3/3 Note 1																
v	On	On	10	3/3	1-4	2/3																
w	On	On	25	2/2	1-4	0/2																
x	Off	Off	0															0/1	0/1	0/1	0/1	
y	Off	Off	0.3-0.8															0/1		0/1		
z	Off	Off	2															0/1	0/1	0/1	0/1	
aa	Off	Off	5															0/1	0/1	0/1	0/1	
bb	Off	Off	10															0/1	0/1	0/1	0/1	

**** Indicates that detector model could not be repowered unshuttered without the detector responding. Tests could not be conducted.

Notes:

1. OFD1F could not be repowered unshuttered. The other two specimens responded to the test condition.
2. OFD1F could not be repowered unshuttered. The other two specimens did not respond to the test condition.

General remarks:

- OFD1F was consistently more sensitive to the test conditions than the other two specimens.
- Intermittent response during the swivel tests (samples in non-latching mode). Responded (continuous) at the end of the swivel test sequence if stopped with the detector viewing the source on-axis.
- Units are very sensitive to the IR Source and Combination IR and UV source at the 5 Hz chopping frequencies and at 10 Hz to a lesser degree. Third specimen tested was very sensitive at 2 Hz.
- The detector model is very sensitive when exposed to the IR Source without the UV Blocking filter from a shuttered condition.

e 1. Summary of Optical Stress Immunity Tests for OFD1

Optical Stress				Results Standard Tests				Results Additional Tests													Note: All swivels were performed at 2	
				Stationary Test		Swivel Test (22.5°/s)		Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			Quartz IR Heater				Min./Max. Voltage
																		at 2 m		at 4 m		
ress ndition	IR Source	UV Source	Chopping Frequency (Hz)	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	Responses, No. Tests
a	Ramp	Off	0	1/3	120	NA		NA	NA	0/1	NA	NA	0/3	NA								
b	On	Off	0	3/3	1-4	1/3		0/1	0/1	1/1	0/1	1/1	0/3	0/3								
c	On	Off	0.3-0.8																			
d	On	Off	2	1/1	1-2	****		****	****	1/1	****	****	0/1	0/1	1/1	1/1	1/1					
e	On	Off	5	3/3	1-4	3/3 Note 1		1/1	0/1	1/1	1/1	1/1	0/3	0/3	1/1	0/1	1/1					
f	On	Off	10	3/3	1-4	1/3 Note 2		1/1	0/1	1/1	0/1	0/1	0/3	0/3	1/1	1/1	0/1					
g	On	Off	25	2/2	1-4	0/2							0/2	0/2	1/1	0/1	0/1					
h	Off	Ramp	0	0/3		NA																
I	Off	On	0	0/3		0/3																
j	Off	On	2	0/1		0/1																
k	Off	On	5	0/3		0/3																
l	Off	On	10	0/3		0/3																
m	Off	On	25	0/2		0/2																
n	Ramp	On	0	0/3		NA																
o	Ramp	On	2	0/1		NA																
p	Ramp	On	5	2/3	180	NA																
q	Ramp	On	10	0/3		NA																
r	Ramp	On	25	0/2		NA																
s	On	On	0	3/3	1-4	0/3																
t	On	On	2	1/1	1-2	****																
u	On	On	5	3/3 Note 1	1-4	3/3 Note 1																
v	On	On	10	3/3	1-4	2/3																
w	On	On	25	2/2	1-4	0/2																
x	Off	Off	0															0/1	0/1	0/1	0/1	
y	Off	Off	0.3-0.8															0/1		0/1		
z	Off	Off	2															0/1	0/1	0/1	0/1	
aa	Off	Off	5															0/1	0/1	0/1	0/1	
bb	Off	Off	10															0/1	0/1	0/1	0/1	

Indicates that detector model could not be repowered unshuttered without the detector responding. Tests could not be conducted.

es:

OFD1F could not be repowered unshuttered. The other two specimens responded to the test condition.

OFD1F could not be repowered unshuttered. The other two specimens did not respond to the test condition.

eral remarks:

FD1F was consistently more sensitive to the test conditions than the other two specimens.

termittent response during the swivel tests (samples in non-latching mode). Responded (continuous) at the end of the swivel test sequence if stopped with the detector viewing the source on-axis.

nits are very sensitive to the IR Source and Combination IR and UV source at the 5 Hz chopping frequencies and at 10 Hz to a lesser degree. Third specimen tested was very sensitive at 2 Hz.

he detector model is very sensitive when exposed to the IR Source without the UV Blocking filter from a shuttered condition.

Table 2. Summary of Optical Stress Immunity Tests for OFD2

Optical Stress				Results Standard Tests				Results Additional Tests										
				Stationary Test		Swivel Test (22.5°/s)		Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			at 2
										(Stationary)	(22.5°/s Swivel)	(11.25°/s Swivel)	(Stationary)	(Swivel)	(Stationary)	(22.5°/s Swivel)	(11.25°/s Swivel)	(Stationary)
Stress Condition	IR Source	UV Source	Chopping Frequency (Hz)	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests	Responses, No. Tests
a	Ramp	Off	0	0/3		NA		NA	NA	0/1	NA	NA	0/3	NA				
b	On	Off	0	0/3		3/3	2-4	1/1	0/1	0/1	1/1	1/1	0/3	0/3				
c	On	Off	0.3-0.8															
d	On	Off	2	1/1	1-2	****		****	****	1/1	****	****	0/1	0/1				
e	On	Off	5	3/3	1-2	****		****	****	1/1	****	****	0/3	0/3				
f	On	Off	10	3/3	1-2	****		****	****	1/1	****	****	0/3	0/3				
g	On	Off	25	0/2		2/2	2-4						0/2	0/2				
h	Off	Ramp	0	0/3		NA												
I	Off	On	0	0/3		0/3												
j	Off	On	2	0/1		0/1												
k	Off	On	5	0/3		0/3												
l	Off	On	10	0/3		0/3												
m	Off	On	25	0/2		0/2												
n	Ramp	On	0	0/3		NA												
o	Ramp	On	2	1/1	3-6	NA												
p	Ramp	On	5	3/3	3-6	NA												
q	Ramp	On	10	3/3	3-6	NA												
r	Ramp	On	25	0/2		NA												
s	On	On	0	0/3		3/3	2-4											
t	On	On	2	1/1	1-2	****												
u	On	On	5	3/3	1-2	****												
v	On	On	10	3/3	1-2	****												
w	On	On	25	0/2		2/2	2-4											
x	Off	Off	0															0/1
y	Off	Off	0.3-0.8															
z	Off	Off	2															0/1
aa	Off	Off	5															0/1
bb	Off	Off	10															0/1

**** Indicates that detector model could not be repowered unshuttered without the detector responding. Tests could not be conducted.

Notes:

nmunity Tests for OFD2

esults Standard Tests				Results Additional Tests													Note: All swivels were performed at 22.5°/s unless otherwise stated.						
tationary Test		Swivel Test (22.5°/s)		Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			Quartz IR Heater at 2 m		Quartz IR Heater at 4 m		Min./Max. Voltage	Blocked Elements Element 1		Blocked Elements Element 2	
nses, ests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests
3		NA		NA	NA	0/1	NA	NA	0/3	NA												
3		3/3	2-4	1/1	0/1	0/1	1/1	1/1	0/3	0/3												
1	1-2	****		****	****	1/1	****	****	0/1	0/1												
3	1-2	****		****	****	1/1	****	****	0/3	0/3												
3	1-2	****		****	****	1/1	****	****	0/3	0/3												
2		2/2	2-4						0/2	0/2												
3		NA																				
3		0/3																				
1		0/1																				
3		0/3																				
3		0/3																				
2		0/2																				
3		NA																				
1	3-6	NA																				
3	3-6	NA																				
3	3-6	NA																				
2		NA																				
3		3/3	2-4																			
1	1-2	****																				
3	1-2	****																				
3	1-2	****																				
2		2/2	2-4																			
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					

e repowered unshuttered without the detector responding. Tests could not be conducted.

able 3. Summary of Optical Stress Immunity Tests for OFD3

Optical Stress				Results Standard Tests				Results Additional Tests										Note: All swivels were performed				
				Stationary Test		Swivel Test (22.5°/s)		Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			Quartz IR Heater at 2 m		Quartz IR Heater at 4 m		Min./Max Voltage
Stress Condition	IR Source	UV Source	Chopping Frequency (Hz)	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	Responses No. Tests
a	Ramp	Off	0	0/3		NA		NA	NA	0/1	NA	NA	0/3	NA								
b	On	Off	0	0/3		0/3		0/1	0/1	0/1	0/1	0/1	0/3	0/3								
c	On	Off	0.3-0.8	0/1		0/1																
d	On	Off	2	0/1		0/1		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1					
e	On	Off	5	0/3		0/3		0/3	0/1	0/1	0/1	0/1	0/3	0/3	0/1	0/1	0/1					
f	On	Off	10	0/3		0/3		0/3	0/1	0/1	0/1	0/1	0/3	0/3	0/1	0/1	0/1					
g	On	Off	25	0/2		0/2							0/2	0/2	0/1	0/1	0/1					
h	Off	Ramp	0	0/3		NA																
I	Off	On	0	0/3		0/3																
j	Off	On	2	0/1		0/1																
k	Off	On	5	0/3		0/3																
l	Off	On	10	0/3		0/3																
m	Off	On	25	0/2		0/2																
n	Ramp	On	0	0/3		NA																
o	Ramp	On	2	0/1		NA																
p	Ramp	On	5	0/3		NA																
q	Ramp	On	10	0/3		NA																
r	Ramp	On	25	0/2		NA																
s	On	On	0	0/3		0/3																
t	On	On	2	0/1		0/1																
u	On	On	5	0/3		0/3																
v	On	On	10	0/3		0/3																
w	On	On	25	0/2		0/2																
x	Off	Off	0															0/1	0/1	0/1	0/1	
y	Off	Off	0.3-0.8															0/1		0/1		
z	Off	Off	2															0/1	0/1	0/1	0/1	
aa	Off	Off	5															0/1	0/1	0/1	0/1	
bb	Off	Off	10															0/1	0/1	0/1	0/1	

**** Indicates that detector model could not be repowered unshuttered without the detector responding. Tests could not be conducted.

Notes:

General remarks:
- Detector model did not respond to any test condition in the standard test procedure (Tests a to w).
- Tried additional tests at 0.3 to 0.8 Hz range. Detector did not respond.
- The detector responded to a krypton bulb penlight. It was difficult to get response and required a RANDOM exposure of the detection elements.
- Blocking both Element 2 and the adjacent test lights produced a BIT failure at power-up and intermittent responses with ambient light conditions.

Immunity Tests for OFD3

Results Standard Tests: Stationary Test (onses, Tests)	Stationary Test: Response Time (s) if any	Swivel Test (22.5°/s): Responses, No. Tests	Swivel Test (22.5°/s): Response Time (s) if any	Results Additional Tests: Swivel Test (11.25°/s): Responses, No. Tests	IR Shutter: Responses, No. Tests	90° Rotation (Stationary) Responses, No. Tests	90° Rotation (22.5°/s Swivel) Responses, No. Tests	90° Rotation (11.25°/s Swivel) Responses, No. Tests	UV Blocking (Stationary) Responses, No. Tests	UV Blocking (Swivel) Responses, No. Tests	Gridded Wheel (Stationary) Responses, No. Tests	Gridded Wheel (22.5°/s Swivel) Responses, No. Tests	Gridded Wheel (11.25°/s Swivel) Responses, No. Tests	Quartz IR Heater at 2 m (Stationary) Responses, No. Tests	Quartz IR Heater at 2 m (Swivel) Responses, No. Tests	Quartz IR Heater at 4 m (Stationary) Responses, No. Tests	Quartz IR Heater at 4 m (Swivel) Responses, No. Tests	Min./Max. Voltage: Responses, No. Tests	Blocked Elements: Element 1 (Stationary) Responses, No. Tests	Blocked Elements: Element 1 (Swivel) Responses, No. Tests	Blocked Elements: Element 2 (Stationary) Responses, No. Tests	Blocked Elements: Element 2 (Swivel) Responses, No. Tests
/3		NA		NA	NA	0/1	NA	NA	0/3	NA									0/2	NA	0/2	NA
/3		0/3		0/1	0/1	0/1	0/1	0/1	0/3	0/3									0/2	0/2	0/2	0/2
/1		0/1																				
/1		0/1		0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1						0/2	0/2	0/2	0/2
/3		0/3		0/3	0/1	0/1	0/1	0/1	0/3	0/3	0/1	0/1	0/1						0/2	0/2	0/2	0/2
/3		0/3		0/3	0/1	0/1	0/1	0/1	0/3	0/3	0/1	0/1	0/1						0/2	0/2	0/2	0/2
/2		0/2							0/2	0/2	0/1	0/1	0/1									
/3		NA																				
/3		0/3																				
/1		0/1																				
/3		0/3																				
/3		0/3																				
/2		0/2																				
)/3		NA																				
)/1		NA																				
)/3		NA																				
)/3		NA																				
)/2		NA																				
)/3		0/3																				
)/1		0/1																				
)/3		0/3																				
)/3		0/3																				
)/2		0/2																				
														0/1	0/1	0/1	0/1					
														0/1		0/1						
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					

Note: All swivels were performed at 22.5°/s unless otherwise stated.

be repowered unshuttered without the detector responding. Tests could not be conducted.

Optical Stress				Results Standard Tests				Results Additional Tests													Note: All swivels
				Stationary Test		Swivel Test (22.5°/s)		Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			Quartz IR Heater			
																		at 2 m		at 4 m	
Stress Condition	IR Source	UV Source	Chopping Frequency (Hz)	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swi Respo No. T
a	Ramp	Off	0	0/6		NA		NA	NA	0/1	NA	NA									
b	On	Off	0	0/6		2/6		0/6	0/1	0/1	1/1	0/1									
c	On	Off	0.3-0.8	6/6		6/6									1/1	1/1	1/1				
d	On	Off	2	1/6	4-5	0/6		0/6	0/1	0/1	0/1	0/1			1/1	1/1	1/1				
e	On	Off	5	0/6		0/6		0/6	0/1	0/1	0/1	0/1			0/1	0/1	0/1				
f	On	Off	10	0/6		0/6		0/6	0/1	0/1	0/1	0/1			0/1	0/1	0/1				
g	On	Off	25	0/2		0/2									0/1	0/1	0/1				
h	Off	Ramp	0	0/3		NA															
I	Off	On	0	0/3		0/3															
j	Off	On	2	0/1		0/1															
k	Off	On	5	0/3		0/3															
l	Off	On	10	0/3		0/3															
m	Off	On	25	0/2		0/2															
n	Ramp	On	0	0/3		NA															
o	Ramp	On	2	0/1		NA															
p	Ramp	On	5	0/3		NA															
q	Ramp	On	10	0/3		NA															
r	Ramp	On	25	0/2		NA															
s	On	On	0	0/3		1/3															
t	On	On	2	0/1		0/1															
u	On	On	5	0/3		0/3															
v	On	On	10	0/3		0/3															
w	On	On	25	0/2		0/2															
x	Off	Off	0															0/1	0/1	0/1	0/1
y	Off	Off	0.3-0.8															1/1		1/1	
z	Off	Off	2															0/1	0/1	0/1	0/1
aa	Off	Off	5															0/1	0/1	0/1	0/1
bb	Off	Off	10															0/1	0/1	0/1	0/1

**** Indicates that detector model could not be repowered unshuttered without the detector responding. Tests could not be conducted.

Notes:

Gemeral remarks:
- OFD4D seemed to be slightly more sensitive than the other units. It responded when swivelled with unchopped IR Source. Needed 2 to 3 swivels to respond. Also, responded when exposed to IR Source chopped at 2 Hz it could be repowered unshuttered and did not respond.
- Tested all six units for tests a, b, and d - f in the above table, no responses except for OFD4D.
- Responded to IR Source chopped at 0.3 to 0.8 Hz (all six units).
- OFD4D responded to Quartz IR heater chopped at 0.3 - 0.8 Hz.

Immunity Tests for OFD4

Results Standard Tests: Stationary Test		Swivel Test (22.5°/s)		Results Additional Tests (Note: All swivels were performed at 22.5°/s unless otherwise stated.): Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			Quartz IR Heater at 2 m		Quartz IR Heater at 4 m		Min./Max. Voltage	Blocked Elements: Element 1		Element 2	
ponses, . Tests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses No. Tests
0/6		NA		NA	NA	0/1	NA	NA											0/2	NA	0/2	NA
0/6		2/6		0/6	0/1	0/1	1/1	0/1											0/2	0/2	0/2	0/2
6/6		6/6									1/1	1/1	1/1						0/2	0/2	0/2	0/2
1/6	4-5	0/6		0/6	0/1	0/1	0/1	0/1			1/1	1/1	1/1						0/2	0/2	0/2	0/2
0/6		0/6		0/6	0/1	0/1	0/1	0/1			0/1	0/1	0/1						0/2	0/2	0/2	0/2
0/6		0/6		0/6	0/1	0/1	0/1	0/1			0/1	0/1	0/1						0/2	0/2	0/2	0/2
0/2		0/2									0/1	0/1	0/1						0/2	0/2	0/2	0/2
0/3		NA																				
0/3		0/3																				
0/1		0/1																				
0/3		0/3																				
0/3		0/3																				
0/2		0/2																				
0/3		NA																				
0/1		NA																				
0/3		NA																				
0/3		NA																				
0/2		NA																				
0/3		1/3																				
0/1		0/1																				
0/3		0/3																				
0/3		0/3																				
0/2		0/2																				
														0/1	0/1	0/1	0/1					
														1/1		1/1						
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					

t be repowered unshuttered without the detector responding. Tests could not be conducted.

sitive than the other units. It responded when swivelled with unchopped IR Source. Needed 2 to 3 swivels to respond. Also, responded when exposed to IR Source chopped at 2 Hz from shuttered condition;
did not respond.
f in the above table, no responses except for OFD4D.
to 0.8 Hz (all six units).
hopped at 0.3 - 0.8 Hz.

Optical Stress: Stress Condition	Optical Stress: IR Source	Optical Stress: UV Source	Optical Stress: Chopping Frequency (Hz)	Results Standard Tests: Stationary Test: Responses, No. Tests	Results Standard Tests: Stationary Test: Response Time (s) if any	Results Standard Tests: Swivel Test (22.5°/s): Responses, No. Tests	Results Standard Tests: Swivel Test (22.5°/s): Response Time (s) if any	Results Additional Tests: Swivel Test (11.25°/s): Responses, No. Tests	IR Shutter: Responses, No. Tests	90° Rotation (Stationary): Responses, No. Tests	90° Rotation (22.5°/s Swivel): Responses, No. Tests	90° Rotation (11.25°/s Swivel): Responses, No. Tests	UV Blocking (Stationary): Responses, No. Tests	UV Blocking (Swivel): Responses, No. Tests	Gridded Wheel (Stationary): Responses, No. Tests	Gridded Wheel (22.5°/s Swivel): Responses, No. Tests	Gridded Wheel (11.25°/s Swivel): Responses, No. Tests	Quartz IR Heater at 2 m (Stationary): Responses, No. Tests	Quartz IR Heater at 2 m (Swivel): Responses, No. Tests	Quartz IR Heater at 4 m (Stationary): Responses, No. Tests	Quartz IR Heater at 4 m (Swivel): Responses, No. Tests	Min/M… Volta… Respo… No. T…
a	Ramp	Off	0	0/3		NA		NA	NA	0/1	NA	NA	0/3	NA								
b	On	Off	0	3/3		0/3		0/1	0/1	1/1	0/1	0/1	0/3	0/3								
c	On	Off	0.3-0.8																			
d	On	Off	2	1/1		****		****	****	1/1	****	****	0/1	0/1								
e	On	Off	5	3/3		****		****	****	1/1	****	****	0/3	0/3								
f	On	Off	10	3/3		****		****	****	1/1	****	****	0/3	0/3								
g	On	Off	25	2/2		****							0/2	0/2								
h	Off	Ramp	0	0/3		NA																
I	Off	On	0	0/3		0/3																
j	Off	On	2	0/1		0/1																
k	Off	On	5	0/3		0/3																
l	Off	On	10	0/3		0/3																
m	Off	On	25	0/2		0/3																
n	Ramp	On	0	0/3		NA																
o	Ramp	On	2	1/1	31-43	NA																
p	Ramp	On	5	3/3	5-10	NA																
q	Ramp	On	10	3/3	16-21	NA																
r	Ramp	On	25	2/2	83-87	NA																
s	On	On	0	3/3		0/3																
t	On	On	2	1/1		****																
u	On	On	5	3/3		****																
v	On	On	10	3/3		****																
w	On	On	25	2/2		****																
x	Off	Off	0															0/1	0/1	0/1	0/1	
y	Off	Off	0.3-0.8															0/1	0/1	0/1	0/1	
z	Off	Off	2															0/1	0/1	0/1	0/1	
aa	Off	Off	5															0/1	0/1	0/1	0/1	
bb	Off	Off	10															0/1	0/1	0/1	0/1	

Note: All swivels were perfo…

**** Indicates that detector model could not be repowered unshuttered without the detector responding. Tests could not be conducted.

Notes:

General remarks:
- Detector model consistently responded to chopped sources at all frequencies.

ess	Results Standard Tests				Results Additional Tests															Note: All swivels were performed at 22.5°/s unless otherwise	
	Stationary Test		Swivel Test (22.5°/s)		Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			Quartz IR Heater				Min./Max. Voltage	Blocked El Element 1	
															at 2 m		at 4 m				
Chopping Frequency (Hz)	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests
0	0/3		NA		NA	NA	0/1	NA	NA	0/3	NA									0/2	NA
0	3/3		0/3		0/1	0/1	1/1	0/1	0/1	0/3	0/3									0/2	
0.3-0.8																					
2	1/1		****		****	****	1/1	****	****	0/1	0/1									0/2	0/2
5	3/3		****		****	****	1/1	****	****	0/3	0/3									0/2	0/2
10	3/3		****		****	****	1/1	****	****	0/3	0/3									0/2	0/2
25	2/2		****							0/2	0/2										
0	0/3		NA																		
0	0/3		0/3																		
2	0/1		0/1																		
5	0/3		0/3																		
10	0/3		0/3																		
25	0/2		0/3																		
0	0/3		NA																		
2	1/1	31-43	NA																		
5	3/3	5-10	NA																		
10	3/3	16-21	NA																		
25	2/2	83-87	NA																		
0	3/3		0/3																		
2	1/1		****																		
5	3/3		****																		
10	3/3		****																		
25	2/2		****																		
0															0/1	0/1	0/1	0/1			
0.3-0.8															0/1	0/1	0/1	0/1			
2															0/1	0/1	0/1	0/1			
5															0/1	0/1	0/1	0/1			
10															0/1	0/1	0/1	0/1			

· model could not be repowered unshuttered without the detector responding. Tests could not be conducted.

ntly responded to chopped sources at all frequencies.

Optical Stress				Results Standard Tests				Results Additional Tests (Note: All swivels were p													
				Stationary Test		Swivel Test (22.5°/s)		Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			Quartz IR Heater			
																		at 2 m		at 4 m	
Stress Condition	IR Source	UV Source	Chopping Frequency (Hz)	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests
a	Ramp	Off	0	0/3		NA		NA	NA	0/1	NA	NA									
b	On	Off	0	0/3		0/3		0/3	0/1	0/1	0/1	0/1									
c	On	Off	0.3-0.8	0/1		0/1		0/1	0/1												
d	On	Off	2	0/1		0/1		0/1	0/1	0/1	0/1	0/1									
e	On	Off	5	0/3		0/3		0/1	0/1	0/1	0/1	0/1									
f	On	Off	10	0/3		0/3		0/1	0/1	0/1	0/1	0/1									
g	On	Off	25	0/2		0/2															
h	Off	Ramp	0	0/3		NA															
i	Off	On	0	0/3		0/3															
j	Off	On	2	0/1		0/1															
k	Off	On	5	0/3		0/3															
l	Off	On	10	0/3		0/3															
m	Off	On	25	0/2		0/2															
n	Ramp	On	0	0/3		NA															
o	Ramp	On	2	0/1		NA															
p	Ramp	On	5	0/3		NA															
q	Ramp	On	10	0/3		NA															
r	Ramp	On	25	0/2		NA															
s	On	On	0	0/3		0/3															
t	On	On	2	0/1		0/1															
u	On	On	5	0/3		0/3															
v	On	On	10	0/3		0/3															
w	On	On	25	0/2		0/2															
x	Off	Off	0															0/1	0/1	0/1	0/1
y	Off	Off	0.3-0.8															0/1	0/1	0/1	0/1
z	Off	Off	2															0/1	0/1	0/1	0/1
aa	Off	Off	5															0/1	0/1	0/1	0/1
bb	Off	Off	10															0/1	0/1	0/1.	0/1

**** Indicates that detector model could not be repowered unshuttered without the detector responding. Tests could not be conducted.

Notes:

General remarks:
- Unit did not respond to any standard test condition.
- Tried additional tests at 0.3 to 0.8 Hz range, the unit did not respond.
- Responded when Element 2 was blocked with exposure to the IR Source from shuttered condition at 2 and 5 Hz. Responded when Element 3 was blocked with exposure to the IR Source from shuttered condition at 2 Hz (this response was difficult to reproduce).
- The standard stationary & 22.5°/s swivel tests a to f were conducted at both the minimum & maximum operating voltages for the 3rd specimen of OFD6.

Immunity Tests for OFD6

Results Standard Tests				Results Additional Tests Note: All swivels were performed at 22.5°/s unless otherwise stated.																		
Stationary Test		Swivel Test (22.5°/s)		Swivel Test (11.25°/s)	IR Shutter	90° Rotation			UV Blocking		Gridded Wheel			Quartz IR Heater				Min./Max. Voltage	Blocked Elements			
														at 2 m		at 4 m			Element 1		Element 2	
onses, Tests	Response Time (s) if any	Responses, No. Tests	Response Time (s) if any	Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(22.5°/s Swivel) Responses, No. Tests	(11.25°/s Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests	(Stationary) Responses, No. Tests	(Swivel) Responses, No. Tests
)/3		NA		NA	NA	0/1	NA	NA										0/4	0/2	NA	0/2	NA
)/3		0/3		0/3	0/1	0/1	0/1	0/1										0/4	0/2	0/2	0/2	0/2
)/1		0/1		0/1	0/1																	
)/1		0/1		0/1	0/1	0/1	0/1	0/1										0/4	0/2	0/2	2/2	0/2
)/3		0/3		0/1	0/1	0/1	0/1	0/1										0/4	0/2	0/2	1/2	0/2
)/3		0/3		0/1	0/1	0/1	0/1	0/1										0/4	0/2	0/2	0/2	0/2
)/2		0/2																				
)/3		NA																				
)/3		0/3																				
)/1		0/1																				
)/3		0/3																				
)/3		0/3																				
)/2		0/2																				
)/3		NA																				
)/1		NA																				
)/3		NA																				
)/3		NA																				
)/2		NA																				
)/3		0/3																				
)/1		0/1																				
)/3		0/3																				
)/3		0/3																				
)/2		0/2																				
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1	0/1					
														0/1	0/1	0/1.	0/1					

be repowered unshuttered without the detector responding. Tests could not be conducted.

condition.
e, the unit did not respond.
with exposure to the IR Source from shuttered condition at 2 and 5 Hz. Responded when Element 3 was blocked with exposure to the IR Source from shuttered condition at 2 Hz
).
ests a to f were conducted at both the minimum & maximum operating voltages for the 3rd specimen of OFD6.

Table 7. Detector response to butane lighter flame (53 mm high flame 300 mm from detector).

Detector Model	Response times (s)		
	Flame	Flame with IR heater at 2 m	Flame with IR heater at 4 m
OFD1	< 1	< 1	< 1
OFD2	2-5	2-5	2-5
OFD3	1	1	1
OFD4	3-6	3-6	3-6
OFD5	< 1	< 1	< 1
OFD6	3	3	3

APPENDIX A

PERFORMANCE SPECIFICATION FOR OPTICAL FIRE DETECTORS

INTRODUCTION

This test specification was prepared based on the results of a study entitled "Study to Develop a Performance Specification for Optical Fire Detectors" dated May 1994 and prepared by the National Research Council of Canada (NRC) and Leber/Rubes Inc. (LRI) for the Department of National Defence, Air Command (DND). The scope of the NRC study was limited to optical characteristics of optical fire detectors (OFDs) which could be influenced by non-fire sources.

The NRC/DND study examined sources of irradiance in Canadian hangar facilities having the potential to activate an OFD. It was concluded that many of the sources with the potential to cause false alarms could be simulated by the use of two common electric lamps: a tungsten halogen incandescent lamp and a metal halide lamp.

In 1995-96, ten OFDs were tested using the draft test procedure. The results of these tests are documented in a report entitled, Pre-Qualification Testing for Optical Fire Detectors for use in Multi-Function Hangars. As a result of this test program, recommendations were made for the modification test procedure. These changes are included in this version of the test procedure.

The objective of the following specification is to provide a practical test program, which qualifies a detector's ability to reject false optical stimuli while recognizing that 100% assurance is impossible.

GLOSSARY

CSA	Canadian Standards Association
FM	Factory Mutual Corporation
IR	Infrared
OFD	Optical fire detector
Optical axis	The centre line of the OFD field of view; i.e., the imaginary line starting at the face of the OFD, midway between the detection elements, and ending at the centre of the prescribed source of radiation.
ULC	Underwriters' Laboratories of Canada
UV	Ultraviolet

WARNING

This test specification and procedure involves the use of fire and UV and IR radiation. UV radiation can be harmful, especially to the eyes and the skin. Necessary safety precautions should be used.

1.0 SCOPE

1.1 General

This specification provides a test procedure and performance criteria to establish an optical fire detector's (OFD) ability to detect a defined fire and establishes a procedure to test the immunity of detectors to non-fire optical radiation sources.

1.2 Application

This specification is intended for application to optical fire detectors (referred to herein as "OFDs") that are used in fire protection applications in aircraft hangars and shelters.

1.3 Definitions

The following definitions apply to terminology in this specification:

.1 Fire Detector

A device that determines the presence of a fire by measuring one or more of its physical properties or associated effects. Optical Fire detectors detect electromagnetic radiation emissions with wavelengths in the ultraviolet (UV), visible, or infrared (IR) portions of the electromagnetic spectrum.

.2 False Alarm Source

Any physical phenomenon, device, process, tool, entity, or utility that emits, transmits, reflects, or directs electromagnetic radiation that may be detected or measured by a fire detector and cause it to signal "fire" when no fire exists, and/or affect a fire detector's reliability in detecting specified fire size at some distance in some elapsed time.

1.4 Performance Requirement

.1 The requirements for fire detection contained herein have been established by the Canadian Department of National Defence - Air Command.

.2 All detectors submitted for testing must be approved by FM, ULC and CSA (see 2.2). Proof of such approvals and listings shall be provided before testing commences.

Symbols, units, and physical constraints used in this specification are in accordance with the International System of Units (SI).

2.0 REFERENCE DOCUMENTS

2.1 Technical Document

For a discussion of OFD operating characteristics and the basis for tests contained in this specification refer to the document titled "Study to Prepare A Performance Specification for Optical Fire Detectors" May 1994.

2.2 Referenced Standards

.1 ULC/O.R.D.-C386-1990, FLAME DETECTORS

.2 FACTORY MUTUAL APPROVAL STANDARD, CLASS 3260/1977, FLAME RADIATION DETECTORS FOR AUTOMATIC SIGNALLING

.3 FACTORY MUTUAL APPROVAL STANDARD, CLASS 3820/1979, ELECTRICAL UTILIZATION EQUIPMENT

.4 CAN/C.S.A. -C22.2 No. 157-92, INTRINSICALLY SAFE AND NON-INCENTIVE EQUIPMENT FOR USE IN HAZARDOUS LOCATIONS

.5 C.S.A. C22.2 No. 142-M1987, PROCESS CONTROL EQUIPMENT, INDUSTRIAL PRODUCTS

.6 C.S.A. C22.2 No. 30-M1986 (reaffirmed 1992), EXPLOSION PROOF ENCLOSURES FOR USE IN CLASS 1 HAZARDOUS LOCATIONS, INDUSTRIAL PRODUCTS

.7 C.S.A. C22.2 No. 25-1966 (reaffirmed 1992), ENCLOSURES FOR USE IN CLASS II GROUPS E, F, AND G HAZARDOUS LOCATIONS

.8 METHODS OF CHARACTERIZING ILLUMINANCE METERS AND LUMINANCE METERS, COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE, PUBLICATION NO. CIE 69, VIENNA, AUSTRIA, 1987

2.3 Order of Precedence

In the event of a conflict between the text of this specification and the references cited herein, the text of this specification shall take precedence.

2.4 Units of Measure

Imperial units are provided for information purposes only. Metric units shall apply.

3.0 OFD FIRE DETECTION RESPONSE TEST

3.1 Purpose

This test will confirm the OFD's ability to detect the test fire established by Air Command.

3.2 Test Configuration

The tests will be conducted indoors to reduce the effect of wind on flame behaviour. This will allow tests to be repeated with minimal variance.

.1 The OFD shall be located at a horizontal distance of 30.5 m (100 ft) from the centre of the test fire pan.

.2 The OFD shall be securely mounted 2.4 m (8 ft) above the pan.

.3 The OFD shall be aimed at a point 0.91 m (3 ft) above the centre of the test fire pan.

.4 The OFD shall be powered at rated supply voltage.

.5 Prepare a 0.61 m x 0.61 m × 0.15 m (2 ft x 2 ft x 0.5 ft) deep pan containing 280 mm (11 in.) water and at least 19 mm (0.7 in.) of JP-4 jet fuel as appropriate to the test and with a black back-drop.

3.3 Methodology

.1 Power the OFD for 5 min prior to starting the tests.

.2 A timer shall be started automatically when the detector is exposed to the pan fire.

.3 The timer will be stopped on detector activation.

.4 The test will be conducted twice at intervals not less than 5 min.

.5 The test in 3.3.1, 3.3.2, 3.3.3, 3.3.4 will be conducted both with the fire shuttered prior to exposure to the detector and unshuttered.

.6 The tests in 3.3.1 to 3.3.5 will be repeated at the limits of the horizontal field of view (FOV) per the manufacturer's field of view specifications less 5°. Only one side of the viewing angle will be

tested. (I.e., a detector with a rated FOV of ± 60° shall be tested at both 0° and at 55° on one side.

.7 The tests in 3.3.1 to 3.3.5 will be repeated at the limits of the vertical FOV per the manufacturer's FOV specifications, less 5°. Only one side of the viewing angle shall be tested.

3.4 Pass/Fail Criteria

The test will be passed successfully if the detector signals the presence of fire within 5 seconds of fuel ignition for tests in configuration 3.2.3. The OFD must pass the test each time the test is carried out.

4.0 OFD FALSE ALARM SUSCEPTIBILITY FROM OPTICAL NON-FIRE SOURCES

4.1 Purpose

These tests will establish the immunity of detectors to a range of non-fire radiation sources.

4.2 Test Conditions

.1 The OFD shall be arranged in the configuration indicated in each test procedure. Manufacturers' recommendations on detector set-up and mounting shall be followed, wherever they do not conflict with other requirements in this performance specification.

.2 All tests will be conducted at both 85% and 110% of rated voltage for the OFD or at the extremes given by the manufacturer. Supply voltage shall be regulated to ± 2% or better.

.3 Sources listed in Table 1 of this specification will be used in various ways to simulate non-fire optical radiation sources (the source) encountered in aircraft hangar environments.

.4 All tests shall be conducted three times.

.5 All tests shall be carried out with bare lamps (no fixtures, lenses, diffusers or covers).

.6 During the tests, the OFD shall be continually monitored for an alarm condition.

.7 Illuminance meters used in testing shall meet the following performance characteristics as specified in publication CIE #69 (see 2.2.8);

.1 spectral error, $f_1' \leq 5\%$,

.2 UV response, $u \leq 2\%$,

.3 IR response, $r \leq 2\%$,

.8 In the event an OFD signals the presence of fire, the following procedure shall be carried out if testing is continued (optional):

.1 The OFD shall remain unshuttered and the OFD supply voltage shall be reduced to zero. The optical source shall remain undisturbed.

.2 The OFD supply voltage shall be restored after at least 1 min.

.3 The OFD shall remain exposed for at least 1 min.

.4 If the OFD signals fire during this period, the test shall be discontinued.

4.3 Pass/Fail Criteria

The OFD shall not respond with a signal representing the presence of fire during any of the following tests. Also, the OFD shall be able to pass the fire detection response test described in 3.0.

4.4 Methods

.1 Set-up

.1 The detector element shall be securely mounted on the axis of rotation of a platform which allows the detector to be swivelled in a horizontal arc of -60° to +60°. The platform shall be marked in increments of 5°. At the midpoint of the arc (i.e., 0°), the OFD shall be aimed at the centre of the prescribed source of radiation.

.2 A rotating chopper shall be used for chopped radiation tests. The chopper diameter shall be at least 610 mm (2 ft). The apparatus shall be driven by a variable,speed motor adjustable to provide chopping at 0, 5, 10 and 25 Hz.

.3 The chopper apparatus shall be placed no more than 610 mm (2 ft) directly in front of the OFD in such a position as to not obstruct any of the radiant flux other than by the "blade" that will completely interrupt the flux from the prescribed irradiance sources.

.4 A black opaque baffle shall extend from floor to ceiling and shall be positioned no more than 102 mm (4 in.) from the chopper blades as shown in Figure 1. The baffle shall contain a circular aperture of 305 mm (12 in.) diameter centred on the optical axis. A second black opaque baffle shall be installed behind the prescribed irradiance sources. Together, these baffles shall shield the OFD from all optical radiation except the direct radiation from the prescribed irradiance sources.

.5 Except for the prescribed irradiance sources, the testing room shall be sealed from all sources of optical radiation, including daylight and electric light sources.

.6 An illuminance meter shall be mounted near the optical axis and outside the view of the OFD. It shall be continually monitored during testing to ensure that the irradiance source remains stable.

NOTE: *Unless otherwise stated, all tests are assumed unchopped, with the blades positioned not to obstruct the prescribed radiation.*

.2 Test Procedures for Tungsten Halogen Source

.1 Detectors shall be subjected to irradiance by Source 1 as described in Table 1 according to the following procedures.

.1 The lamp shall be mounted approximately 1.2 m (4 ft) above the floor or any reflecting surface. The OFD shall be mounted at the same height.

The lamp and OFD shall be separated approximately the distance specified in Table 1.

The OFD shall be oriented such that the source and OFD are directly facing each other.

.2 The OFD shall be powered for at least 1 min at the minimum operating voltage stated in 4.2.2.

.3 The source shall be powered by a DC supply voltage which applies voltage in at least 50 increments while causing a linearly increasing photometric output from the prescribed source over a period of 5 min.

.4 After the illuminance meter indicates a stable source (i.e., ± 5% measured over 5 min), the separation between the source and detector shall

be adjusted to obtain the illuminance criteria specified in Table 1.

.5 The detector shall be shuttered for at least 1 min to shield the OFD from all optical radiation.

.6 The shutter shall be removed to expose the OFD to the prescribed source for at least 30 s.

.7 The power to the OFD shall be switched off and on at least 5 consecutive times at intervals of 2 s (i.e., 1 s off then 1 s on).

.8 The detector shall be swivelled back and forth continuously at least five (5) times within the arc described in 4.4.1.1. The rate of movement shall be 45°/2 s.

Note: A pause of 1 s or less is permitted during reversals in direction, to reduce mechanical stress.

.9 The OFD shall be re-oriented such that it directly faces the irradiance source. During re-orientation, the OFD shall remain exposed to the source.

.10 Steps 4.4.2.1.4 to 4.4.2.1.9 shall be repeated with the chopper operated at each of 5, 10 and 25 Hz.

.11 Steps 4.4.2.1.4 to 4.4.2.1.10 shall be repeated with the detector power source providing the maximum voltage described in 4.2.2.

.2 Detectors shall be irradiated as per 4.4.2 except that a UV-blocking filter shall be inserted in the optical path to block exposure to the weak UV emissions from the light source. Appropriate baffling shall be used to exclude all indirect radiation from the lamp. The UV-blocking filter shall be characterized as follows: ≥ 99.9% blocking below 1 μm; ≥ 85% average and 75% minimum transmittance from 1 μm to 6 μm. The filter described in Figure 2 is suitable. The tests described in steps 4.4.2.1.1 to 4.4.2.1.11 shall be repeated during exposure to the filtered tungsten halogen lamp

.3 The tests in 4.4.2.1 and 4.4.2.2 shall be repeated with the detector rotated 90° about the horizontal axis.

.4 If the detector has more than 1 distinct detection element, the tests described in 4.4.2.1 to 4.4.2.3 shall be repeated with each detection element blocked, in turn, from all direct and indirect radiation from the source.

.3 Test Procedures for Metal Halide Source

.1 Detectors shall be subjected to irradiance by Source 2 as described in Table 1 according to the following procedures.

.1 The lamp shall be mounted approximately 1.2 m (4 ft) above the floor or any reflecting surface. The OFD shall be mounted at the same height.

The lamp and OFD shall be separated approximately the distance specified in Table 1.

The OFD shall be oriented such that the source and OFD are directly facing each other

.2 The OFD shall be powered for at least 1 min at the minimum operating voltage stated in 4.2.2.

.3 The source shall then be powered as required by its manufacturer. The OFD will remain exposed to this source as it stabilizes.

.4 After at least 10 min, and after the illuminance meter indicates a stable source (± 5% measured over 5 min), the separation between the source and detector shall be adjusted to obtain the illuminance criteria specified in Table 1.

.5 The detector shall be shuttered for at least 1 min to shield the OFD from all optical radiation.

.6 The shutter shall be removed to expose the OFD to the prescribed source for at least 30 s.

.7 The power to the OFD shall be switched off and on at least 5 consecutive times at intervals of 2 s (i.e., 1 s off then 1 s on).

.8 The detector shall be swivelled back and forth continuously at least five (5) times within the arc described in 4.4.1.1. The rate of movement shall be 45°/2 s.

Note: A pause of 1 s or less is permitted during reversals in direction, to reduce mechanical stress.

.9 The OFD shall be re-oriented such that it directly faces the irradiance source. During re-orientation, the OFD shall remain exposed to the source.

.10 Steps 4.3.1.4 to 4.3.1.9 shall be repeated with the chopper operated at each of 5, 10 and 25 Hz.

.11 Steps 4.3.1.4 to 4.3.1.10 shall be repeated with the detector power source providing the maximum voltage described in 4.2.2.

.2 The tests in 4.4.3.1 shall be repeated with the detector rotated 90° about the horizontal axis.

.3 If the detector has more than 1 distinct detection element, the tests described in 4.4.3.1 and 4.4.3.2 shall be repeated with each detection element blocked, in turn, from all direct and indirect radiation from the source.

.4 Test Procedures for Table 1 Combined Sources

.1 Sources 1 and 2 in Table 1 and described, as item 3, in the table, shall be tested according to the following procedures.

.1 Both lamps shall be mounted approximately 1.25 m (4 ft) above the floor or any reflecting surface. The OFD shall be mounted at the same height.

The lamps and OFD shall be separated approximately the distance specified in Table 1.

The OFD shall face the lamps.

.2 The OFD shall be powered for at least 1 min at the minimum operating voltage stated in 4.2.2.

.3 Source 2 shall then be powered as required by its manufacturer. The OFD will remain exposed to this source as it stabilizes.

.4 After at least 10 min, and after the illuminance meter indicates a stable source (± 5% measured over 5 min), the separation between Source 2 and

the OFD shall be adjusted to obtain the illuminance criteria specified in Table 1 for item 2 of the table.

.5 Source 1 shall then be powered by a DC supply voltage which applies voltage in at least 50 increments while causing a linearly increasing photometric output from the prescribed source over a period of 5 min.

.6 After the illuminance meter indicates a stable source (i.e., ±5% measured over 5 min), the separation between Source 1 and the OFD shall be adjusted to obtain the maximum illuminance criteria specified in Table 1 for item 3 of the table.

.7 The OFD shall be shuttered for at least 1 min to shield the OFD from all optical radiation.

.8 The shutter shall be removed to expose the OFD to the prescribed radiation for at least 30 s.

.9 The power to the OFD shall be switched off and on at least 5 consecutive times at intervals of 2 s (i.e., 1 s off then 1 s on).

.10 The detector shall be swivelled back and forth continuously at least five (5) times within the arc described in 4.4.1.1. The rate of movement shall be 45°/2 s.

Note: A pause of 1 s or less is permitted during reversals in direction, to reduce mechanical stress.

.11 The OFD shall be re-oriented such that it directly faces the lamps. During re-orientation, the OFD shall remain exposed to the sources of radiation.

.12 Steps 4.4.1.4 to 4.4.1.11 shall be repeated with the chopper operated at each of 5, 10 and 25 Hz.

.13 Steps 4.4.1.4 to 4.4.1.13 shall be repeated with the OFD power source providing the maximum voltage described in 4.2.2.

.2 The tests in 4.4.4.1 shall be repeated with the detector rotated 90° about the horizontal axis.

.3 If the detector has more than 1 distinct detection element, the tests described in 4.4.4.1 to 4.4.4.2 shall be repeated

with each detection element blocked, in turn, from all direct and indirect radiation from the source.

.5 Optional Preliminary Screening using Penlight

.1 An illuminated 3.0 V penlight shall be waved approximately 10 mm from the detection element(s) of the detector.

.2 The pass/fail criteria describe in 4.3 shall apply for this informal test.

TABLE 1

NON-FIRE IRRADIATION SOURCES

Source / Description	Illuminance at OFD (lux)	Approximate Distance from OFD (m (ft))	Irradiance* at OFD ($\mu W/cm^2/nm$)	
			in IR spectral band (4.35 μm)	in UV spectral band (211 nm)
1) Tungsten Halogen, 1000 W	4160	0.8 (2.5)	0.10	
2) Metal Halide, 1000 W, with glass envelope removed, and shaded by layered aluminium screening	2.4	2 (6.5)		1.2×10^{-3}
3) Combined output from 1 and 2 above	2.4 to 4162	2 (6.5)	0.10	1.2×10^{-3}

*Note: Irradiance is normalized by bandwidth at ½ height.

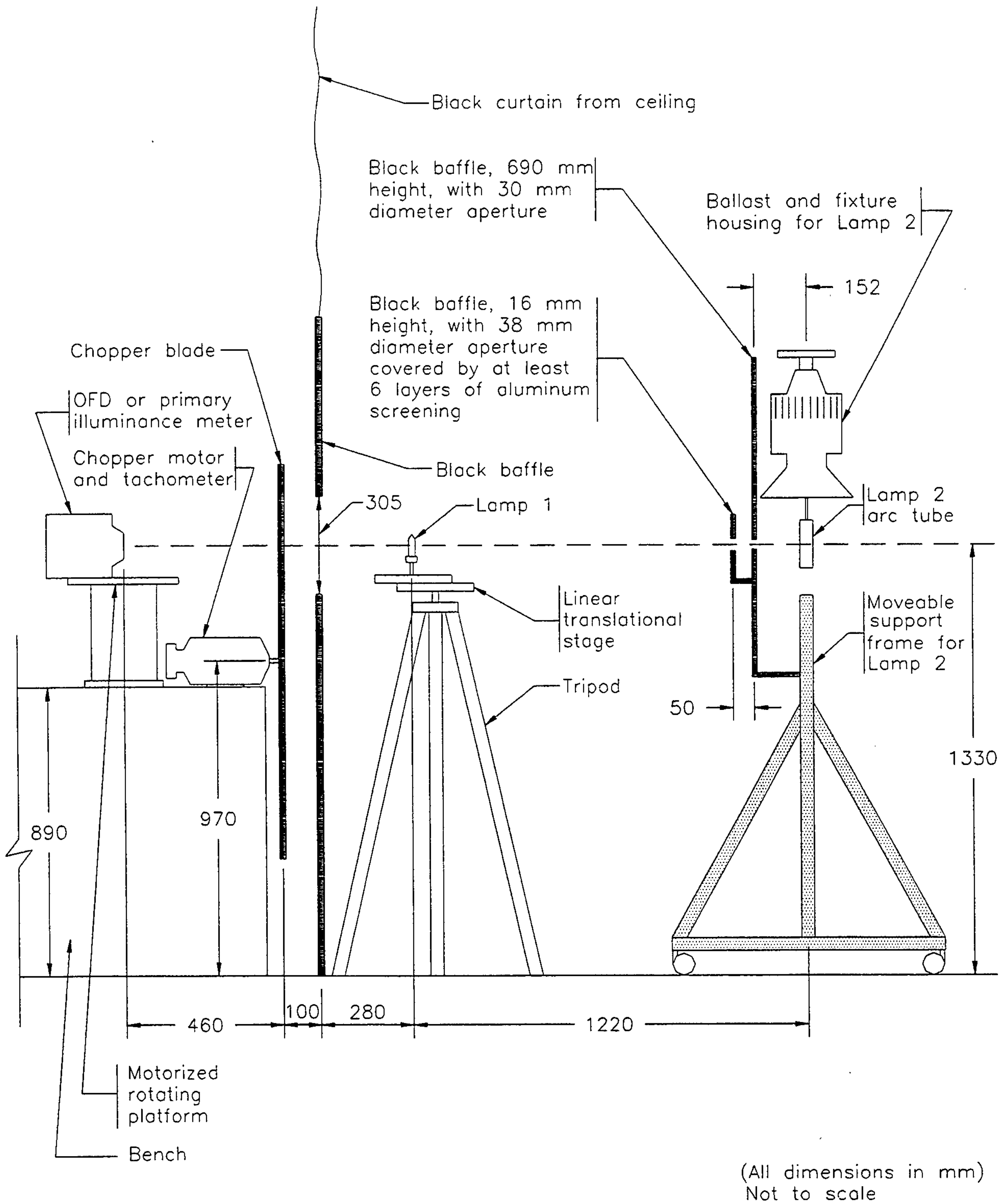


Figure A1. Elevation cross section of suggested apparatus for optical immunity tests.

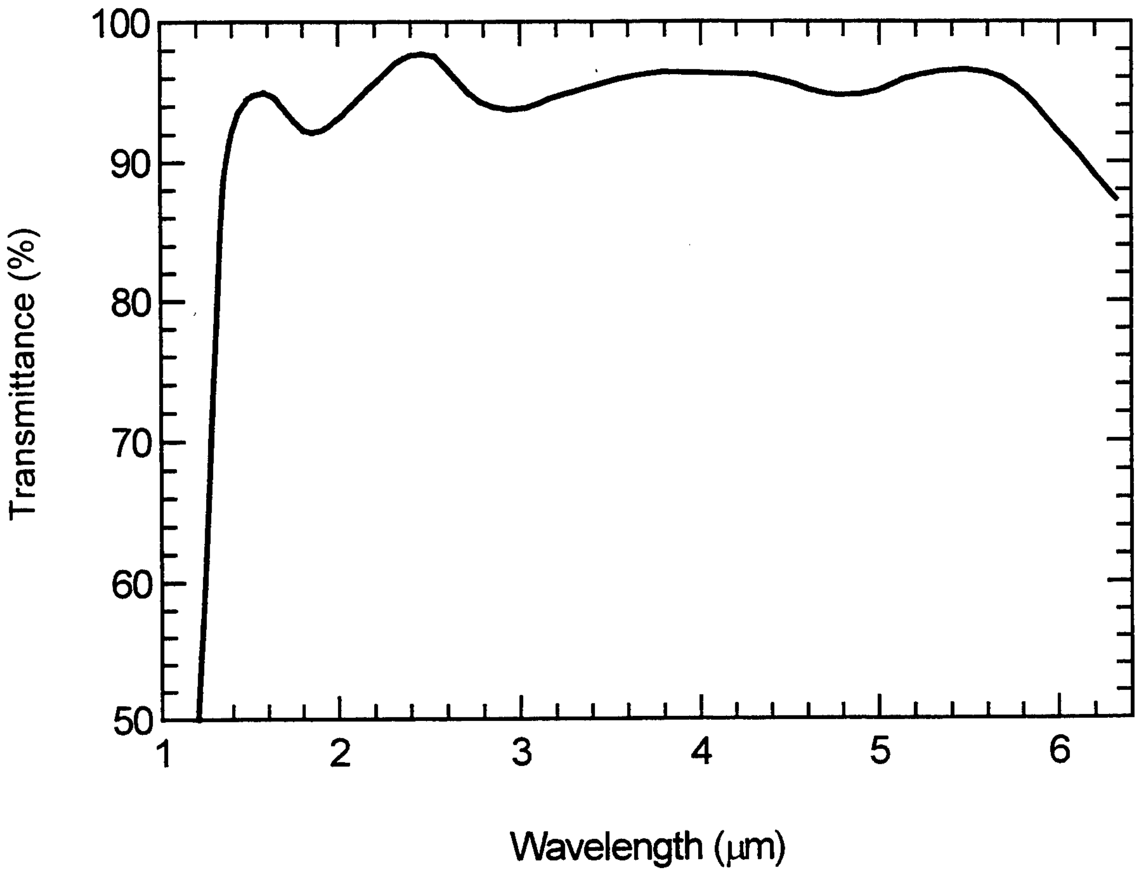


Figure A2. Spectral transmittance of a suitable UV-blocking filter for step 4.4.2.2. This particular filter is a silicon window with multiple anti-reflection coatings on both surfaces.

Appendix F

Point Source Model Calculations and Input

This appendix includes an example "Rule Sheet" and "Input Sheet" from the TK Solver program used for solving the transient point source model. The transient point source model calculates the surface temperature of a target positioned a defined distance from a fire (represented as a point source).

Rule Sheet

```
Comment    ;Heat transfer model to determine the damage to an aircraft adjacent to a Class B fire.
Comment    ;Model assumes uniform temperature of target material and adiabatic boundary at back surface
Comment    ;Model uses a point source assumption for the radiation from the fire to the target

        I = ELT()
        Place('Ts,I+1)=Ts
        If I<=1 then to=0 else to='t[I-1]
        Δt = t-to
        If I<=1 then Tso=Tsinitial else Tso='Ts[I-1]
        Ts = Tso + (1/Cs/ρs/δ) * Δt * (Q12 - Q20 - Qconv)
        Q12 = Q*Xr / (4*PI()*d^2)
        Q20 = ϵ*σ*(Ts^4-To^4)
        Qconv = h*(Ts -To)
```

Input Sheet

St	Input	Name	Output	Unit	Comment
L		Q12	.002853364	kW/m^2	Radiant heat flux from fire (1) to object
L		Q20	4.49535E-6	kW/m^2	Radiant heat flux from object (2) to surroundings
L		Qconv	9.08509E-6	kW/m^2	Convective heat flux from object (2) to surroundings
	.01	h		kW/m^2*K	Heat transfer coefficient
	5.67E-11	σ		kW/m^2*K^4	Stefan-Boltzmann constant
LGuess	301	Ts		K	Surface temperature of object (2)
		Tso	301	K	Previous value of material surface temperature
	301	Tsinitial		K	Initial value of material surface temperature
	301	To		K	Ambient Temperature
	.875	Cs		kJ/kg*K	Specific heat capacity of material
	2770	ρs		kg/m^3	Density of material (target)
	.8	ϵ			Emissivity of material
	.00081	δ		m	Thickness of material
	3	d		m	Dis. from center of pool to target
		I	1		Element number
		to	0	s	Previous time value
		Δt	1	s	Time step
L	1	t		s	Time
	.4	Xr			Radiative fraction
L	1	Q		kW	Heat release rate of fire

Appendix G

Draft Performance Specification for Optical Fire Detectors Used in Military Hangars

PERFORMANCE SPECIFICATION FOR OPTICAL FIRE DETECTORS

INTRODUCTION

In 1994, an initial performance specification for optical fire detectors (OFDs) was prepared by the National Research Council of Canada (NRC) and Leber/Rubes Inc. (LRI) for the Canadian Department of National Defence, Air Command (DND). The test procedure was based on the premise that the sources of optical emissions in hangars with the potential to produce a detector response could be simulated by the use of two common electric lamps: a tungsten halogen incandescent lamp and a metal halide lamp.

In 1995-96, ten OFDs were tested by NRC for DND using the draft test procedure. As a result of this test program, recommendations were made for the modification of the test procedure. In 1998, the revised test procedure was used to determine the optical immunity of 6 OFDS as part of a project undertaken by the Naval Facilities Engineering Command (NAVFAC) to improve fire protection systems in military aircraft hangars. Based on the results of the two test programs, recommendations were made for the modification to the test procedure. The recommended changes are included in this edition of the test procedure.

The objective of the following specification is to provide a practical test program, which qualifies a detector's ability to reject false optical stimuli while recognizing that 100% assurance is impossible.

GLOSSARY

CSA	Canadian Standards Association
DLS	Diret line of sight
FM	Factory Mutual Corporation
IR	Infrared
OFD	Optical fire detector
Optical axis	The centre line of the OFD field of view; i.e., the imaginary line starting at the face of the OFD, midway between the detection elements, and ending at the centre of the prescribed source of radiation.
ULC	Underwriters' Laboratories of Canada
UV	Ultraviolet

WARNING

This test specification and procedure involves the use of fire and UV and IR radiation. UV radiation can be harmful, especially to the eyes and the skin. Necessary safety precautions should be used.

1.0 SCOPE

1.1 General

This specification provides a test procedure and performance criteria to establish an optical fire detector's (OFD) ability to detect a defined fire and establishes a procedure to test the immunity of detectors to non-fire optical radiation sources.

1.2 Application

This specification is intended for application to optical fire detectors (referred to herein as "OFDs") that are used in fire protection applications in aircraft hangars and shelters.

1.3 Definitions

The following definitions apply to terminology in this specification:

.1 Fire Detector

A device that determines the presence of a fire by measuring one or more of its physical properties or associated effects. Optical Fire Detectors detect electromagnetic radiation emissions with wavelengths in the ultraviolet (UV), visible, or infrared (IR) portions of the electromagnetic spectrum.

.2 Optical Stress Source

Any physical phenomenon, device, process, tool, entity, or utility that emits, transmits, reflects, or directs electromagnetic radiation that may be detected or measured by a fire detector and cause it to respond when no fire exists, and/or affect a fire detector's reliability in detecting specified fire size at some distance in some elapsed time.

1.4 Performance Requirement

.1 The requirements for fire detection contained herein have been established by the Naval Facilities Engineering Command (NAVFAC).

.2 All detectors submitted for testing must be approved or listed by a nationally recognized testing laboratory. Proof of such approvals and listings shall be provided before testing commences.

Symbols, units, and physical constraints used in this specification are in accordance with the International System of Units (SI).

2.0 REFERENCE DOCUMENTS

2.1 Referenced Standards

.1 METHODS OF CHARACTERIZING ILLUMINANCE METERS AND LUMINANCE METERS, COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE, PUBLICATION NO. CIE 69, VIENNA, AUSTRIA, 1987

.2 MIL-T-83133D military specification JP-8 fuel.

2.2 Order of Precedence

In the event of a conflict between the text of this specification and the references cited herein, the text of this specification shall take precedence.

2.3 Units of Measure

Imperial units are provided for information purposes only. Metric units shall apply.

3.0 OFD FIRE DETECTION RESPONSE TEST

3.1 Purpose

This test will confirm the OFD's ability to detect the test fire established by NAVFAC.

3.2 Test Configuration

The tests will be conducted indoors to reduce the effect of wind on flame behavior. This will allow tests to be repeated with minimal variance.

3.2.1 An OFD specimen shall be tested at the following locations and orientations.

OFD located at a horizontal distance of 30.5 m (100 ft) from the center of the test fire and aimed at a point 1.22 m (4 ft) above the center of the test fire.

OFD located at a horizontal distance of 30.5 m (100 ft) from the center of the test fire and aimed 40 degrees in the horizontal field of view with respect to a point 1.22 m (4 ft) above the center of the test fire.

OFD located at a horizontal distance of 45.7 m (150 ft) from the center of the test fire and aimed at a point 1.22 m (4 ft) above the center of the test fire.

OFD located at a horizontal distance of 45.7 m (150 ft) from the center of the test fire and aimed 40 degrees in the horizontal field of view with respect to a point 1.22 m (4 ft) above the center of the test fire.

Multiple tests can be conducted with the same OFD specimen positioned at the four locations/orientations described above, or four separate OFD specimens positioned at the four locations/orientations can be used in the same test.

3.2.2 All OFDs evaluated in the fire detection response tests (Section 3) must be evaluated per Section 4 (OFD Immunity to Optical Stresses from Non-fire Sources).

3.2.3 The OFDs shall be securely mounted 3.0 m (10 ft) above the base of the fire.

3.2.4 The OFD(s) shall be configured as it will be installed in the Navy hangar application intended. If the OFD has different settings corresponding to different field of view depths, the OFD may be configured for the specified location distance as tested (i.e., 30.5 m and 45.7 m). Otherwise, all configuration settings must be the same for all location/orientation fire tests and the Section 4 tests for OFD Immunity to Optical Stresses from Non-fire Sources.

3.2.5 The OFD(s) shall be powered at rated supply voltage.

3.2.6 Two pan fires shall be used: 1) a 0.48 x 0.48 m x 0.1 m deep pan containing 2.5 cm of water and at least 0.75 cm of JP-8 fuel (250 kW fire) and 2) a 0.91 x 0.91 x 0.1 m deep pan containing 2.5 cm of water and at least 0.75 cm of JP-8 fuel (900 kW fire).

3.2.7 The JP-8 fuel shall meet MIL-T-83133D. The fuel and the water shall have an initial temperature of 23 ± 3°C (73.5 ± 5°F)

3.2.8 The ignition source shall consist of a shielded acetylene torch flame. The flame shall be approximately 25 cm long and 5 cm in diameter. The flame will be shielded from the detectors using a metal plate or shroud

attached to the torch. The ignition source shall be applied to the center of the fuel surface until sustained burning of the fuel is achieved.

3.2.9 A chopped UV/IR source shall consist of a set of three, 500 W halogen work lamps with the glass covers removed. Chopping is to be achieved by rotating a segmented drum around the axis of the row of lamps positioned horizontal to the ground. The chopping frequency shall be 4 to 5 Hz. The lamps are to be angled to face directly at the detectors. The chopped UV/IR source will be positioned at 10 m from the OFD, in-line between the OFD and the fire.

3.2.10 The chopped IR source shall consist of a 1500 W quartz heater. Chopping is to be achieved by rotating a segmented drum around the axis of the heating element when positioned horizontal to the ground. The chopping frequency shall be 4 to 5 Hz. The heating element shall be fully visible to the OFD. The chopped IR source will be positioned at 10 m from the OFD, in-line between the OFD and the fire.

3.2.11 An obstruction will be used to block a portion of the fire from the view of the OFD(s). The obstruction shall block all of the flame from a height of 0.3 to 2.3 m above the top edge of the pan.

3.2.12 An arc welding event will consist of a man using an arc welder set to 100A and a 6013, 0.318 cm (1/8 in.) organic binder rod along a piece of steel set on the floor. During the test, two welding rods will be used in succession with no more than a 20 second down time in between changing the rods. Welding shall begin prior to but no more than 10 seconds before ignition. The welding shall take place 16 m from the OFD, in-line between the OFD and the fire. There shall be no obstructions between the welding source and the OFD.

3.3 Methodology

3.3.1 Power the OFD(s) for 5 minutes prior to starting the tests.

3.3.2 The time of OFD response shall be measured from the time of ignition. Ignition shall be defined as the point in time at which the ignition source (3.2.7) is applied to the fuel surface.

3.3.3 Each test will be conducted three times at intervals not less than 5 minutes.

3.3.4 An OFD at each location/orientation defined in 3.2.1 will be exposed to each of the fire exposures stated in Table 1.

3.4 Pass/Fail Criteria

The test will be passed successfully if the detectors respond according to all of the alarm criteria in Table 1 for all consecutively repeat tests.

4.0 OFD IMMUNITY TO OPTICAL STRESSES FROM NON-FIRESOURCES

4.1 Purpose

These tests will establish the immunity of detectors to a range of non-fire radiation sources.

4.2 Test Conditions

.1 The OFD shall be arranged in the configuration indicated in each test procedure. Manufacturers' recommendations on detector set-up and mounting shall be followed, wherever they do not conflict with other requirements in this performance specification.

.2 All tests will be conducted at the nominal rated voltage for the OFD (typically 24 V). Supply voltage shall be regulated to 2% or better.

.3 Sources listed in Table 2 of this specification will be used in various ways to simulate non-fire optical radiation sources (the source) encountered in aircraft hangar environments.

.4 All tests shall be conducted once for three test specimens. The same test specimen(s) used in the fire tests (Section 3) shall be used in the tests of Section 4.

.5 All tests shall be carried out with bare lamps (no fixtures, lenses, diffusers or covers).

.6 During the tests, the OFD shall be continually monitored for an alarm condition.

.7 Illuminance meters used in testing shall meet the following performance characteristics as specified in publication CIE #69 (see 2.2.8);

   .1 spectral error, $f_1' = 5\%$,

   .2 UV response, $u = 2\%$,

   .3 IR response, $r = 2\%$,

.8 In the event an OFD responds to the optical stress, the following procedure shall be carried out if testing is continued (optional):

.1 The OFD shall remain unshuttered and the OFD supply voltage shall be reduced to zero. The optical source shall remain undisturbed.

.2 The OFD supply voltage shall be restored after at least 1 min.

.3 The OFD shall remain exposed for at least 1 min.

.4 If the OFD signals fire during this period, the test shall be discontinued.

4.3 Pass/Fail Criteria

The OFD shall not respond with a signal representing the presence of fire during any of the following tests. Also, the OFD shall be able to pass the fire detection response test described in 3.0. The same test specimen(s) used in the fire tests must be used in Section 4.

4.4 Methods

.1 Set-up

.1 The detector element shall be securely mounted on the axis of rotation of a platform which allows the detector to be swivelled in a horizontal arc of -60° to +60°. The platform shall be marked in increments of 5°. At the midpoint of the arc (i.e., 0°), the OFD shall be aimed at the centre of the prescribed source of radiation.

.2 A rotating chopper with 8 alternating open and closed sections shall be used for chopped radiation tests. The chopper diameter shall be at least 610 mm (2 ft). The apparatus shall be driven by a variable speed motor adjustable to provide chopping at 0, 2, 5, 10 and 25 Hz. For the tests with the gridded wheel, the four open sections of the chopper shall be covered with a partially open steel grid with 13 mm diameter holes on 19 mm centres.

.3 The chopper apparatus shall be placed no more than 610 mm (2 ft) directly in front of the OFD in such a position as to not obstruct any of the radiant flux other than by the "blade" that will completely interrupt the flux from the prescribed irradiance sources.

.4 A black opaque baffle shall extend from floor to ceiling and shall be positioned no more than 102 mm (4 in.) from the chopper blades as shown in Figure G1. The baffle shall contain a circular aperture of 610 mm (24 in.) diameter centered on the optical axis. A second black opaque baffle shall be installed behind the prescribed irradiance sources. Together, these baffles shall shield the OFD from all optical radiation except the direct radiation from the prescribed irradiance sources.

.5 Except for the prescribed irradiance sources, the testing room shall be sealed from all sources of optical radiation, including daylight and electric light sources.

.6 An illuminance meter shall be mounted near the optical axis and outside the view of the OFD. It shall be continually monitored during testing to ensure that the irradiance source remains stable.

NOTE: *Unless otherwise stated, all tests are assumed unchopped, with the blades positioned not to obstruct the prescribed radiation.*

.2 Test Procedures for Tungsten Halogen Source

.1 Detectors shall be subjected to irradiance by Source 1 as described in Table 1 according to the following procedures.

.1 The lamp shall be mounted approximately 1.2 m (4 ft) above the floor or any reflecting surface. The OFD shall be mounted at the same height.

The lamp and OFD shall be separated approximately the distance specified in Table 2.

The OFD shall be oriented such that the source and OFD are directly facing each other.

.2 Source 1 shall then be powered by a programmable DC supply voltage at the maximum prescribed voltage.

.3 After the illuminance meter indicates a stable source (i.e., ±5% measured over 5 min), the separation between the source and detector shall be adjusted to obtain the illuminance criteria specified in Table 1.

.4 The OFD shall be powered for at least 1 min at the nominal operating voltage stated in 4.2.2.

.5 The source shall be powered by a programmable DC supply voltage which applies voltage in at least 50 increments while causing a linearly increasing photometric output from the prescribed source over a period of 5 min.

.6 The detector shall be shuttered for at least 1 min to shield the OFD from all optical radiation.

.7 The shutter shall be removed to expose the OFD to the prescribed source for at least 30 s.

.8 The detector shall be swivelled back and forth continuously at least five (5) times within the arc described in 4.4.1.1. The rate of movement shall be 45°/2 s.

Note: A pause of 1 s or less is permitted during reversals in direction, to reduce mechanical stress.

.9 The OFD shall be re-oriented such that it directly faces the irradiance source. During re-orientation, the OFD shall remain exposed to the source.

.10 Steps 4.4.2.1.4 to 4.4.2.1.9 shall be repeated with the chopper operated at each of 2, 5, 10 and 25 Hz.

.11 Steps 4.4.2.1.4 to 4.4.2.1.9 shall be repeated with a half-gridded chopper operated at each of 2, 5, 10 and 25 Hz.

.12 Steps 4.4.2.1.4 to 4.4.2.1.11 shall be repeated for three test specimens.

.3 Test Procedures for Metal Halide Source

.1 Detectors shall be subjected to irradiance by Source 2 as described in Table 2 according to the following procedures.

.1 The lamp shall be mounted approximately 1.2 m (4 ft) above the floor or any reflecting surface. The OFD shall be mounted at the same height.

The lamp and OFD shall be separated approximately the distance specified in Table 2.

The OFD shall be oriented such that the source and OFD are directly facing each other

.2 The source shall then be powered as required by its manufacturer.

.3 After at least 10 min, and after the illuminance meter indicates a stable source (± 5% measured over 5 min), the separation between the source and detector shall be adjusted to obtain the illuminance criteria specified in Table 1. After calibration, the source shall be turned off.

.4 The OFD shall be powered for at least 1 min at the nominal operating voltage stated in 4.2.2.

.5 The Source shall be powered with the OFD exposed to the source as it stabilizes.

.6 The detector shall be shuttered for at least 1 min to shield the OFD from all optical radiation.

.7 The shutter shall be removed to expose the OFD to the prescribed source for at least 30 s.

.8 The detector shall be swivelled back and forth continuously at least five (5) times within the arc described in 4.4.1.1. The rate of movement shall be 45°/2 s.

Note: A pause of 1 s or less is permitted during reversals in direction, to reduce mechanical stress.

.9 The OFD shall be re-oriented such that it directly faces the irradiance source. During re-orientation, the OFD shall remain exposed to the source.

.10 Steps 4.3.1.4 to 4.3.1.9 shall be repeated with the chopper operated at each of 2, 5, 10 and 25 Hz.

.11 Steps 4.3.1.4 to 4.3.1.10 shall be repeated for three test specimens.

.4 Test Procedures for Table 2 Combined Sources

.1 Sources 1 and 2 in Table 2 and described, as item 3, in the table, shall be tested according to the following procedures.

.1 Both lamps shall be mounted approximately 1.25 m (4 ft) above the floor or any reflecting surface. The OFD shall be mounted at the same height.

The lamps and OFD shall be separated approximately the distance specified in Table 2.

The OFD shall face the lamps.

The lamps shall be offset such that the OFD is provided a clear view of both sources.

.2 The OFD shall be powered for at least 1 min at the nominal operating voltage stated in 4.2.2.

.3 Source 2 shall then be powered as required by its manufacturer. The OFD will remain exposed to this source as it stabilizes.

.4 After at least 10 min, and after the illuminance meter indicates a stable source (± 5% measured over 5 min), the separation between Source 2 and the OFD shall be adjusted to obtain the illuminance criteria specified in Table 2 for item 2 of the table.

.5 Source 1 shall then be powered by a programmable DC supply voltage at the maximum prescribed voltage.

.6 After the illuminance meter indicates a stable source (i.e.,±5% measured over 5 min), the separation between Source 1 and the OFD shall be adjusted to obtain the maximum illuminance criteria specified in Table 2 for item 3 of the table. After calibration, Source 1 will be turned off.

.7 The OFD shall be shuttered for at least 1 min to shield the OFD from all optical radiation.

.8 Source 1 shall be powered by a programmable DC supply voltage which applies voltage in at least 50 increments while causing a linearly increasing photometric output from the prescribed source over a period of 5 min.

.9 The OFD shall be shuttered for at least 1 min to shield the OFD from all optical radiation.

.10 The shutter shall be removed to expose the OFD to the prescribed radiation for at least 30 s.

.11 The detector shall be swivelled back and forth continuously at least five (5) times within the arc described in 4.4.1.1. The rate of movement shall be 45°/2 s.

Note: A pause of 1 s or less is permitted during reversals in direction, to reduce mechanical stress.

.12 The OFD shall be re-oriented such that it directly faces the lamps. During re-orientation, the OFD shall remain exposed to the sources of radiation.

.13 Steps 4.4.1.7 to 4.4.1.12 shall be repeated with the chopper operated at each of 2, 5, 10 and 25 Hz.

.14 Steps 4.4.1.7 to 4.4.1.13 shall be for three test specimens.

.2 Test Procedures for Quartz IR Source

.1 Detectors shall be subjected to irradiance by Source 4 as described in Table 1 according to the following procedures.

.1 The Quartz IR heater shall be mounted approximately 1.2 m (4 ft) above the floor or any reflecting surface. The OFD shall be mounted at the same height.

The Quartz IR heater and OFD shall be separated approximately the distance specified in Table 1.

The OFD shall be oriented such that the source and OFD are directly facing each other.

.2 The OFD shall be powered for at least 1 min at the nominal operating voltage stated in 4.2.2.

.3 The Quartz IR heater shall be powered to provide a nominal output of 1500 W.

.4 The Quartz IR heater shall be located 2 m (6.5 ft) from the OFD.

.5 The detector shall be shuttered for at least 1 min to shield the OFD from all optical radiation.

.6 The shutter shall be removed to expose the OFD to the prescribed source for at least 30 s.

.7 The detector shall be swivelled back and forth continuously at least five (5) times within the arc described in 4.4.1.1. The rate of movement shall be 45°/2 s.

Note: A pause of 1 s or less is permitted during reversals in direction, to reduce mechanical stress.

.8 The OFD shall be re-oriented such that it directly faces the irradiance source. During re-orientation, the OFD shall remain exposed to the source.

.9 Steps 4.4.2.1.5 to 4.4.2.1.8 shall be repeated with the chopper operated at each of 2, 5, 10 and 25 Hz.

.10 Steps 4.4.2.1.5 to 4.4.2.1.9 shall be repeated for three test specimens.

TABLE 1
FIRE EXPOSURE TESTS

No.	Fire	Test Scenario	Alarm Criteria
1	0.48 x 0.48 m JP-8 pan fire	Unobstructed	$\leq$ 45 s at 30.5 m DLS and 45.7 m DLS
2	0.91 x 0.91 m JP-8 pan fire	Obstructed 0.3 to 2.3 m above lip of pan.	$\leq$ 50 s at all locations and orientations
3	0.48 x 0.48 m JP-8 pan fire	Chopped UV/IR source in field of view	$\leq$ 45 s at 30.5 m DLS and 45.7 m DLS
4	0.91 x 0.91 m JP-8 pan fire	Chopped IR source in field of view	$\leq$ 50 s at all locations and orientations

Note: DLS - Direct line of sight

TABLE 2
NON-FIRE IRRADIATION SOURCES

Source / Description	Illuminance at OFD (lux)	Approximate Distance from OFD (m (ft))	Irradiance* at OFD ($\mu W/cm^2/nm$)	
			in IR spectral band (4.35 μm)	in UV spectral band (211 nm)
1) Tungsten Halogen, 1000 W	4160	0.8 (2.5)	0.10	
2) Metal Halide, 1000 W, with glass envelope removed, and shaded by layered aluminium screening	2.4	2 (6.5)		1.2 H 10^{-3}
3) Combined output from 1 and 2 above	2.4 to 4162	2 (6.5)	0.10	1.2 H 10^{-3}
4) Quartz IR heater (1500 W)		2 (6.5)		

*Note: Irradiance is normalized by bandwidth at 2 height.

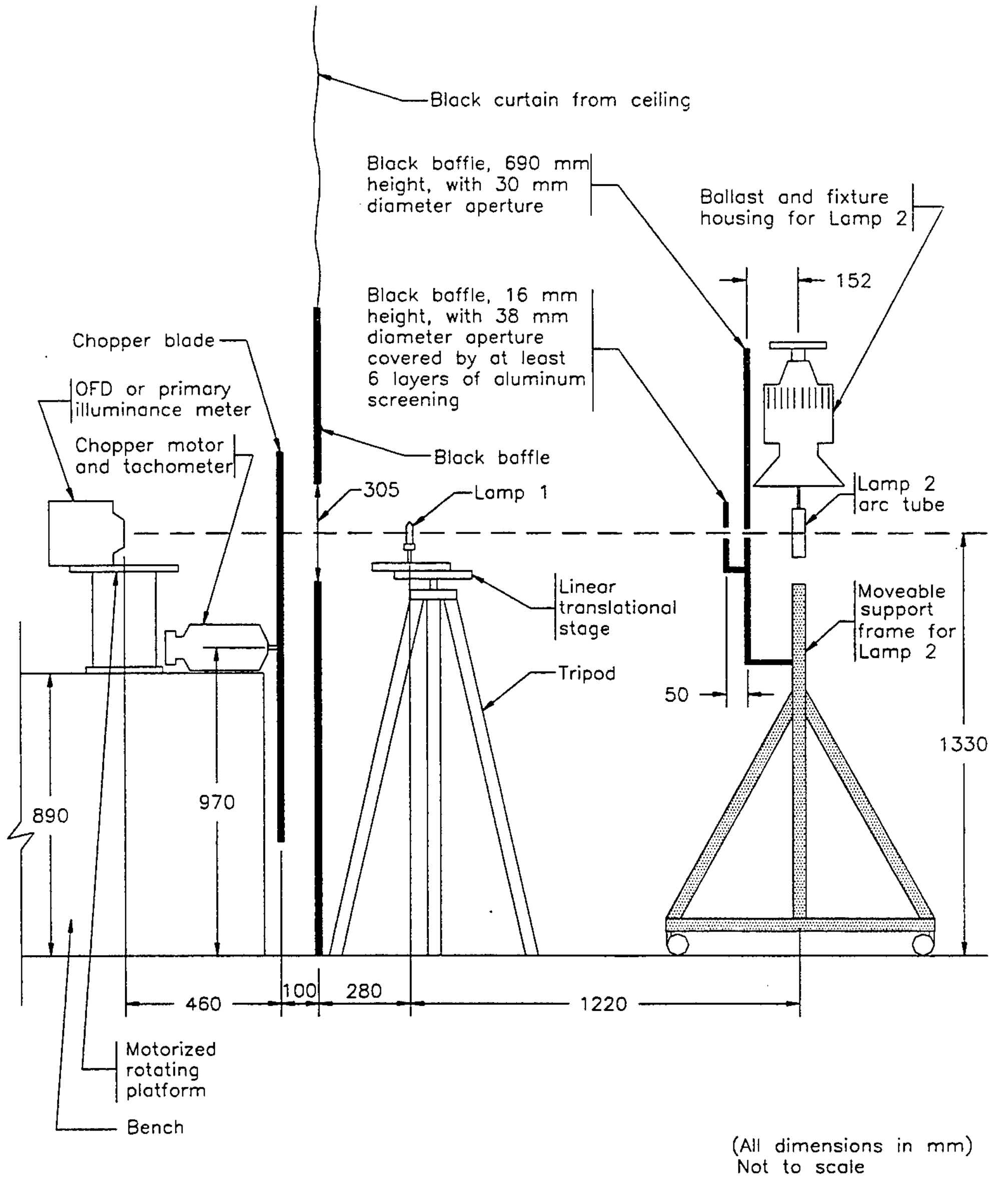


Figure G1. Elevation cross section of suggested apparatus for optical immunity tests.

Appendix H

Performance Specification Test Fire Calculations

This appendix presents the calculations for determining the pan sizes presented in the draft test specification. The pans were sized to provide equivalent fires as the unconfined spill fire scenarios. Pan fire fuel burning rate data obtained from this test program was used in these calculations.

The mass burning rate per unit area of fuel, $\dot{m}''$, can be calculated as using the measured heat release rate, Q, the measured pan area, A, and the heat of combustion reported in Table 1 of Section 5.3 of the report, $\Delta h_c = 4300$ kJ/kg:

$$\dot{m}'' = \frac{\dot{Q}}{A \Delta h_c} \tag{H1}$$

Using the test results of the pan fires, mass burning rates were calculated for the three JP-8 pan fire scenarios conducted. The results are presented in Table H1.

Table H1. Calculated mass burning rates per unit area for JP-8 pan fires.

Pan	Pan Area (m^2)	Heat Release Rate (kW)	$\dot{m}''$ (kg/m^2s)
0.3 x 0.3 m	0.093	~ 100	0.025
0.6 x 0.6 m	0.37	~ 350 to 400	0.025 to 0.029
0.9 m diameter	0.657	~600 to 750	0.021 to 0.027

Based on the test results, the burning rate per unit area for JP-8 pan fires was taken to be 0.025 kg/m^2s. This value is approximately half of the values reported by Babrauskas (0.051 and 0.054) for JP-4 and JP-5 pool fires of infinite diameter (actually, > ~ 2 m) [1]. When compensating for the diameter per Babrauskas' correlations, the burning rates per unit area based on this test data are still low. The comparison of the data is shown in Table H2. The JP-4 and JP-5 data would be expected to bracket the burning rate data for JP-8. The difference may be attributed to limited data upon which the Babrauskas correlations are based.

Table H2. Comparison of calculated fuel burning rates based on test data and values calculated based on published data by Babrauskas.

Pan	Equivalent Dia. (m)	JP-8 $\dot{m}''$ (kg/m^2s)	JP-4* $\dot{m}''$ (kg/m^2s)	JP-5* $\dot{m}''$ (kg/m^2s)
0.3 x 0.3 m	0.344	0.025	0.036	0.023
0.6 x 0.6 m	0.686	0.025 to 0.029	0.047	0.036
0.9 m diameter	0.9	0.021 to 0.027	0.049	0.041

* Values calculated based on correlations and data presented by Babrauskas [1].

Using the experimentally derived value of 0.025 (kg/m^2s) for the burning rate, equation H1 was used to calculate the pan size for a 250 kW and 900 kW fire. The corresponding pan sizes are 0.48 x 0.48 m and 0.91 x 0.91 m, respectively.

Reference

1. Babrauskas, V., "Burning Rates," *The SFPE Handbook of Fire Protection Engineering*, Second Edition, P. DiNenno, Editor-in-Chief, National Fire Protection Association, Boston, MA, 1995.